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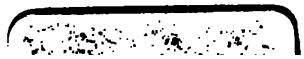

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LVIII.

SESSION 1878-79.—PART IV.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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ERRATA.

Vol. liv., p. 220, line 15, *for* "0·18 ton" *read* "18 tons."

Vol. lv., p. 337, line 8, *for* "designed by the President of" *read* "approved by."

Vol. lvi., p. 208, line 12 from bottom, *for* "(*ante* p. 8)" *read* "(*ante* p. 176)."

„ p. 296, line 4 from bottom, after "ratio of" add "the chemical equivalents of the."

Vol. lvii., p. 45, lines 15 and 16, *for* "crossed a dock entrance and not a river," *read* "crossed a river and not a dock entrance."

„ p. 337, last line, *for* "1,607 to 1,707" *read* "1·607 to 1·707."

„ p. 338, line 4, *for* "1,713 to 1808" *read* "1·713 to 1·808."

„ „ „ 5, *for* (£109·6 to £115·7 per mile)" *read* "(2*s.* 2·25*d.* to 2*s.* 7*d.* per mile.)"

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1878-79.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

April 29, 1879.

JOHN FREDERIC BATEMAN, F.R.SS.L.&E., President, in the Chair.

No. 1634.—"Street Carriageway Pavements."—By GEORGE FREDERICK DEACON,[1] M. Inst. C.E.

As a branch of Civil Engineering street paving has never occupied a very high place. It is true that, when once the conditions of its maximum economy and efficiency are ascertained, exceptional skill is not required to put them into practice; but those conditions have rarely received at the hands of engineers the consideration in detail which they demand; and when the very high degree is duly appreciated, in which the welfare of the community is influenced by the method of paving adopted, it must be conceded that the divergent opinions and practice at present extant should at once be formulated and fairly compared. The Proceedings of the Institution have contained no discussion on the subject for many years. The Author therefore proposes to state his practice, and to tabulate its results in a manner which, if generally adopted, will remove much of the present difficulty of making accurate comparisons between the various classes of pavements and the different modes of constructing them.

The present Paper will be confined to Street Carriageways, and will exclude the consideration of such roads as form lines of communication between centres of population, or between

[1] The discussion upon this Paper was taken together with that upon the one following.

scattered rural dwellings and market towns, railway termini, or harbours. The former division of the subject of road making offers abundant matter for consideration in a single Paper, and the latter division has been ably dealt with by Mr. W. H. Wheeler,[2] M. Inst. C.E. Up to page 20 of this Paper the details and cost of construction of certain pavements will be given, and their relative advantages will then be generally considered.

I.—Construction.

Carriageways of Hammer-dressed Stone, or Set Pavements.

Figure of Sets.—Sets when properly secured in position and formed of the hardest stones are so durable, even under the heaviest traffic, that it is not worth while to make them more than from 6 to 7½ inches deep. Two depths are employed in Liverpool: the first for moderate traffic, averaging 6¼ inches; and the second for the heaviest traffic, averaging 7¼ inches. In relation to its other dimensions, a set should be of such depth that when the wheel of a heavy cart passes over one edge of its upper surface it should not tend to tip. The resultant direction of pressure of the load and adjoining sets should, in short, always tend to depress the whole set vertically. Where, as frequently happens, this precaution is neglected, the maintenance of a uniform surface is impossible. This consideration would lead *per se*, for sets of the above-mentioned depth, to a surface of 4 or 5 inches square. Sets of this figure remain comparatively stable, even on bad foundations and with defective joints. There are other influences, however, which lead to a modification of this form. It is desirable that the width of each set measured along the street should be small. If it is large, a horse drawing a heavy load attempting to find a joint slips back, and requires an exceptionally wide joint to pull him up. The wide joint induces increased wear of the upper corners of the sets, and increased noise.

In practice, the Author has found that, for all but the softer stones, upon which, even if there were no joints, horses could travel with facility, it is desirable that the widths of the sets should be such that four taken at random, and placed side by side, will not measure more than 14 inches across. As in this measurement the irregular projections of the sets are taken into account, the average

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[2] "Roads and Highways; their history, construction, cost, repair, and management." By W. H. Wheeler, M. Inst. C.E. Journal of the Royal Agricultural Society of England, vol. xii., part 2, page 382. London, 1876.

surface width is less than 3 inches; and if with this width the surfaces are square, the number of longitudinal joints is so great that it is impossible for the paviors to break joint properly, and at the same time to keep the joints close, without much loss of time in selecting each set as it is placed. Two or more longitudinal joints in nearly the same line, or a single rather wide longitudinal joint, almost invariably initiates a groove.

The square form which, for stability, would otherwise have been the best, has therefore been altered in the Author's practice to an oblong of the width above stated, and of a length varying from 5 to 7 inches, which, when the set is fixed in position in the manner about to be described, is not found to be too great in relation to the depth to secure stability.

These conclusions may be summarised as follows:

Hard stone, in which joints are necessary for foothold.

	Depth.	Width.	Length.
	Inches. Inches.	Sets. Inches.	Inches. Inches.
Sets for moderate traffic . .	6 to 6½	4 to 14	5 to 7
Sets for heaviest traffic . .	7 „ 7½	4 „ 14	5 „ 7

Softer stones, in which joints are unnecessary for foothold.

	Depth.	Width.	Length.
	Inches. Inches.	Sets. Inches.	Inches. Inches.
Sets for light traffic or inclines	6 to 6½	3 to 14	5 to 7

Materials of Sets.—Among the igneous, plutonic, and metamorphic rocks are to be found a great variety of stones suitable for paving, of all degrees of hardness, brittleness, and toughness; but the durability under traffic, the tendency to wear round rather than flat and to become slippery, are dependent upon no conditions which can readily be foreseen. The size and distribution of the crystals, the nature and hardness of the constituent minerals, operate in such a manner that two opposite combinations often produce nearly the same result; while rocks of nearly equal hardness frequently behave very differently under traffic. The specific gravity, moreover, appears to afford no assistance in the determination.

The only sedimentary rocks which it is desirable to use for street pavements are some portions of the millstone grits and other more laminated grits of the coal measures, and the use of these should be confined to steep gradients and to streets of little traffic. Specimens of rocks used in Liverpool for paving are exhibited, and in the following table (page 4) are stated the localities from which

Locality from which Sets are obtained.	Description of Stone.[1]	Specific Gravity.	Behaviour under Traffic.
A. Penmaenmawr, Carnarvonshire (old quarry): sets from this quarry have not been laid in Liverpool since 1871	Very close-grained. (*Quartz, felspar, hornblende*)	2·75	More durable than any rock known to the Author, but becomes very slippery under traffic. Corners apt to wear round by chipping off.
B. Penmaenmawr, sets now used	Close-grained. (*Quartz, felspar, hornblende*)	2·82	Very durable; suitable for the heaviest traffic in streets of moderate gradients. Corners apt to wear round by chipping off.
C. Port Nant, Carnarvonshire	Close-grained. (*Quartz, felspar, hornblende*)	2·70	Very durable; nearly as hard, and not so slippery, as B.
D. Yr Eifl, Llanaelliaiarn, Carnarvonshire	Close-grained. (*Quartz, felspar, hornblende*)	2·63	A very tough rock, nearly as hard, and not so slippery, as B. Corners not so apt to wear round. Suitable for the heaviest traffic in streets of moderate gradient.
E. Pistyll, Carnarvonshire .	Close-grained. (*Quartz, felspar, hornblende*)	2·60	Wears similarly to C.
F. Llanbedrog, Carnarvonshire	Coarse-grained. (*Felspar, quartz, hornblende*)	2·53	Has not been long used in Liverpool. It is not slippery, and is moderately durable.
G. Festiniog, Carnarvonshire .	Rather coarse-grained. (*Felspar, quartz, hornblende*)	2·59	Has not been long used in Liverpool. It is not slippery, and appears to be as nearly as durable as F.
H. Minnford, Portmadoc, Carnarvonshire	Close-grained. (*Quartz, felspar, hornblende*)	2·9	Free from slipperiness: harder than J, but in other respects similar.
J. Gimblet, Pwllheli, Carnarvonshire	Rather coarse-grained. (*Hornblende, felspar, quartz*)	2·9	Not so hard as H; free from slipperiness, and wears to a very flat surface.
K. Newry, Ireland	Coarse-grained. (*Felspar, quartz, hornblende*)	2·7	These are softer rocks than any of the foregoing; but where the cost is small, they are satisfactory for inclines, or streets of light traffic. They are not slippery.
L. Bessbrook, Ireland . . .	Coarse-grained. (*Felspar, quartz, hornblende*)	2·65	
M. Dalbeatie, Scotland . .	Very coarse-grained. (*Quartz, felspar, hornblende*)	2·7	Softer than K and L; not slippery.
N. Bagbie, Creetown, Scotland	Coarse-grained. (*Quartz, felspar, hornblende*)	2·62	
O. Lancashire	Millstone grit	2·44	Only suitable for the lightest traffic. May be employed with advantage in streets of very steep gradient.

[1] The Author is indebted to Mr. Isaac Roberts, F.G.S., for the determination of the order of the relative volumes of the constituent minerals, in which order they are placed in the second column of the table.

they are obtained, their lithological characters, and their behaviour under traffic, so far as is known to the Author, when paved as described in this Paper.

Mode of Jointing.—Until 1871 the joints of Liverpool set pavements were simply filled with gravel, well worked down with a tool called a cramming iron. In many towns a grouting of hydraulic lime and gravel is brushed into the joints. The first method answers moderately well for streets of light traffic; the second binds the gravel to some extent, but in very few cases do the sets fail to work loose, and the grouting to become disintegrated, even if the vibration of the traffic, which is generally too soon turned upon the pavement, has ever allowed it to set firmly. Joints made according to the first method are always very pervious to water; those made by the second method are less so: but, owing to the fact that the grouting is almost always disintegrated, they are far from impervious.

In pavements of which the foundations are not of concrete, imperviousness is of the utmost importance; for where water can percolate to the substratum, that substratum is softened, and under continuous traffic portions of it work up through the joints, or press the sets upwards in places where the traffic is lighter. In either case hollows are formed. Unless a strong concrete foundation is employed, it is useless to attempt to make the joints impervious with a brittle material such as cement or lime; and so far as the Author is aware, the only thoroughly impervious joints under such circumstances have been formed with various asphaltic compositions. For more than thirty years the authorities of many towns in Lancashire and Yorkshire have made the joints of their pavements by first filling them with clean gravel, and then pouring in a boiling asphalt of pitch and creosote oil.

A crucial examination of many classes of pavements satisfied the Author, in 1871, that those jointed with asphalt retained their figures better, and wore out less rapidly, than any others. This method of jointing is often very indifferently performed; and, as it is scarcely known in the south of England, it may be useful to describe in detail the mode which experience has shown to be the best. The sets, which should be dry, are paved as closely as possible, having regard to the maintenance of each course in a straight line, upon whatever foundation may have been prepared for them. If upon a concrete foundation, about ¾ inch of sharp sand is allowed to intervene between the pavement and the foundation.

When a considerable area is ready, it is covered with clean, dry,

and hard gravel, which has been passed through a ¾-inch riddle and rejected by a ¼-inch riddle. When this gravel has been well brushed into the joints, the sets are thoroughly rammed with the old-fashioned two-handled vertical rammer, which the rammerman swings between his legs. The effect of this is to shake the gravel down, and cause it in most places to disappear; more gravel is then added, and the ramming repeated. After a third, if not after the second, gravelling and ramming, each set should be perfectly firm. The vibration of the ramming shakes the pebbles even into the narrowest spaces, where they act as most efficient wedges. The firmness of the pavement even at this stage is generally surprising to those who see it for the first time.

The asphalt is prepared in boilers on wheels. The large-sized boilers for making carriageways contain about 25 cwt. of asphalt, while the small sizes used for repairs contain from 5 to 10 cwt. The coal-tar pitch employed costs in Liverpool about 1*s.* 6*d.* per cwt. Care must be taken that it is not too brittle; foremen accustomed to the work can judge of this quality by biting it. Pitch, from which so much of the essential oil has been expelled as to make it brittle, and to raise its melting point too high, will never assume that permanently plastic condition, when boiled with oil, which is necessary to prevent subsequent cracking. The oil employed for softening the pitch is the impure carbolic acid or dead oil from the distillation of coal tar. It is known in the trade as creosote, or creosote oil, but is quite distinct from true creosote. It costs about 2½*d.* per gallon. About fifty gallons of creosote oil are required for every ton of pitch, but the exact quantity depends chiefly upon the quality of the pitch. During the process of boiling, the consistency of the asphalt is determined from time to time by cooling small portions in water and kneeding it in the fingers.

The hot asphalt is drawn off into iron buckets, each containing rather less than 1 cwt. Each bucket is carried to the prepared pavement on a carrying bar between two men, and the contents ladled out. No attempt is made to run it into the joints without covering the whole surface. The asphalt penetrates the smallest interstices, and for many hours after the joints are apparently full it continues to sink until only a thin coating is left on the surface, with here and there a hole, which is filled from a small ladle. Lastly, the pavement is finished by covering it with small sharp gravel, which, with much of the remaining pitch, is subsequently squeezed into the joints by the traffic.

The cost per square yard in Liverpool of pavements laid as

above described, exclusive of the foundation and of excavation, is as follows:

Impervious pavement with asphalt joints, as now laid in Liverpool.

			s.	d.
0·31	ton	Stone sets, 7½ inches deep, including cartage, at 28*s.*	8	8
0·064	„	Gravel for bedding, ¾ inch thick . „ „ 6*s.* 6*d.*	0	5
0·015	„	Pitch . . . . . „ „ 30*s.*	0	5·25
0·6	gallon	Oil. . . . . „ „ 2½*d.*	0	1·5
0·002	ton	Coke . . . . . „ „ 12*s.*	0	0·25
0·018	„	Shingle, dried and riddled . . . . . „ 7*s.*	0	1·5
		Labour.	0	8·5
			10	6
		Add establishment expenses, 8 per cent.	0	10
		Total per square yard	11	4

	s.	d.
Similar pavement with sets 6½ inches deep per square yard .	10	4

Pervious pavements with ordinary gravel joints as formerly laid in Liverpool (present prices per square yard):

			s.	d.
0·31	ton	Stone sets, 7½-inches deep, including cartage, at 28*s.* .	8	8
0·096	„	Gravel for bedding, 1 inch thick „ „ 6*s.* 6*d.*	0	7·5
0·02	„	„ „ joints „ „ „ 6*s.*	0	1·5
		Labour	0	5
			9	10
		Add establishment expenses, 8 per cent.	0	9
		Total per square yard	10	7

	s.	d.
Similar pavement with sets 6½ inches deep per square yard .	9	6

Foundation.

It has already been stated that in 1871 the Author gave the preference to asphalt-jointed pavements. Prior to that time they had never been employed in Liverpool; and as the Liverpool traffic was probably heavier than that of any other town, it became necessary to consider whether, in addition to the change in the method of jointing, any alteration should be made in the foundations of the carriageways.

In the oldest Liverpool streets the sets had simply been paved upon an old macadamised surface, but in those more recently constructed, it had been usual to form foundations after the manner

adopted by Telford for highways, of which the wearing material was broken stone. Those foundations consisted of rough stones 10 or 12 inches long, set on end by hand to the proper curvature of the road. The tops of any projecting stones were broken off, and the hollows filled in with smaller stones and rolled. The traffic was then allowed to pass for several weeks before the pavement was laid.

	s.	*d.*
Present cost per yard of hand-pitched foundation, as formerly adopted in Liverpool.	1	5
Add for establishment expenses, 8 per cent.	0	1·36
Total per square yard	1	6·36

Apart from all other considerations, this method of forming the foundation was obviously undesirable, where it was necessary to reconstruct the pavements of existing streets, on account of the long time occupied in consolidation.

In Manchester, where the pavements were, on the whole, the most perfect the Author had seen in any of the towns examined, the sets were simply laid upon a well consolidated bed covered with cinders, and the impervious joints were trusted to prevent the unequal sinking so generally caused by water soaking into the foundations; but where heavy traffic constantly passed over the same lines, the sets did undoubtedly sink beneath those lines. The Author decided, therefore, that, for the heavier traffic at least, it was desirable to employ concrete foundations. Subsequently, asphalt-jointed pavements were tried, both with and without concrete foundations, with so marked an advantage in favour of the concrete that it has since been used in all except the quietest streets, and within the last six years about 200,000 superficial yards have been laid. The methods adopted have varied slightly from time to time, but experience has led for some years past to the following practice: The concrete employed is either Portland cement or bituminous concrete. Before reconstructing a carriageway for heavy traffic, parts of the existing foundation are exposed in many different places. If, as often happens, no part of this foundation is worth retaining, the ground is excavated to the proper depth for Portland cement concrete. If, as sometimes happens, either an old macadamised road, or an old hand-pitched foundation, is met with at a sufficient depth below the base of the proposed pavement, Portland cement concrete is still employed. If, on the other hand, the macadamised surface or the hand-pitching reaches in places close up to the pavement,

so that only a very thin stratum of concrete can be used without removing it, bituminous concrete, incapable of cracking, is used in preference to the comparatively brittle Portland cement concrete.

Portland Cement Concrete Foundations.—Where, as in the case of a carriageway foundation, a comparatively thin stratum of concrete is required, it is especially necessary that that stratum should be uniform in strength, or homogeneous, if the term can be properly applied to such a mixture. The most perfect concrete which the Author has produced is made as follows:

The ground on which the foundation is to be laid is first well watered; upon it is then scattered a layer of wet broken stone like coarse macadam; upon this layer is spread with the spade a thin stratum of cement mortar, and upon the mortar a further layer of wet broken stones. The upper layer of broken stones is then beaten into the lower layer with beaters like large spades, with straight handles 4 feet 4½ inches long and flat beaters of sheet iron about 12 inches square and ¼ inch thick. Another stratum of mortar, followed by a third of stone, is then laid, and the beating process continued; and so on, until the required thickness is attained, when the surface is first beaten and then finished by rubbing with the beaters to the proper curvature of the carriageway. The surface is thus made as smooth and uniform as a plastered wall. By this method a complete but thin coating of mortar is left round every stone, and a maximum of strength is attained with a minimum of cement. When cut through, no sign of lamination is found. The mortar is composed of six parts by measure of gravel and one of Portland cement. The broken stones, measured separately, represent about eight parts, but when the whole is mixed and beaten together, the proportion of stones and gravel to set cement is as 11 to 1. This, however, includes the upper layer, in which there is more than the average proportion of mortar.

No cement is allowed to be used the tensile strength of which is less than 800 lbs. on a section of 2¼ square inches, or which sets in less than three hours so firmly as to take no impression from a Vicat's needle, having an area of $\frac{1}{400}$th part of a square inch and a weight of 2½ lbs., or of which more than 10 per cent. is rejected by a 50-gauge sieve. Though seldom laid more than 6 inches in thickness, this concrete is so strong that when, for the purpose of laying new service pipes, or of reaching old ones, it has to be removed, it is simply cut out with a saw-pick, just as slabs of stone are quarried, in pieces about 3 feet square. When the excavation has been refilled and rammed, these blocks are relaid, cemented to the

old concrete, and paved upon at once. On the following day the traffic is allowed to pass over them, and no subsequent sinking has ever been known to take place—a striking contrast to the old system, in which the paving over trenches in streets of considerable traffic was generally relaid three times, and sometimes oftener.

The Author desires to lay great stress upon the homogeneity and strength of the concrete, which renders it possible to saw it out, and upon the smoothness and exact form of the surface, which not only insures uniformity of the subsequent paving, but guides the workmen in replacing cut out blocks.

Experience has shown that concrete, made in the manner described, should not be paved upon for at least eight days after being placed *in sitû*. Eight days is a serious addition to the time during which part of a street must be closed for pavement, but in order to obtain the best result the inconvenience must be endured; moreover no real advantage is gained by paving one half at a time, and leaving less than one half open to traffic. It is impossible under such circumstances to do the work so well; it is impossible to do it so quickly; and the blocks which take place in the traffic create, in the Author's opinion, more inconvenience on the whole than if all the traffic sought from the first a different route. The most important thoroughfares in the greatest forwarding town in the world have been repaved with Portland cement concrete foundations within the last six years. The idea of closing them entirely was at first not contemplated, and when it was adopted many complaints were naturally made. Those who know the central 3 miles of Liverpool dock streets can well understand this; but it will be shown later on that the loss was rapidly recouped; and since the first few thousand yards of the new pavements were opened, warehouse owners and carriers have alike submitted, without complaint, to the temporary loss, for which they obtain so great a return.

Owing to the mode in which the broken stone is added, the quantity of concrete to be mixed on the boards is less by about 50 per cent. than under the ordinary system. Hitherto the work has been performed by hand, as follows: Each man stands before a board 4 feet square with three sides 8 inches high. The boards are placed in the segment of a circle, touching, or nearly touching, each other, with their open edges towards the centre. Behind and between every pair of boards is a frame of galvanised iron, supporting a galvanised iron cistern of about 3 cubic feet capacity. From each cistern project two

pipes, fitted with roses and taps, one over each board. Hinged to the back of each board is a box, having a capacity of 1½ cubic feet. This box has a strong handle, by which its contents may be readily tipped on to the board. Behind the boards are tipped the gravel and the cement. Suppose the boards to be lettered from A to G. Box A is filled from behind by the gravel man, then B, then C, and so on to G. Mixer A pulls over box A with his spade, and spreads out the gravel, over which the cement boy, who follows the gravel man from A to G, scatters the cement from a hemispherical vessel, containing ½ cubic foot. Mixer A then turns over his gravel and cement, until thoroughly incorporated. He next turns the tap on to a bare part of the board, and shovels over the mixture, scattering it among the spray. An experienced man will scatter the mixture at such a rate that when all turned over it will have exactly the required dampness. The tap is then turned off, and very little more labour is necessary to make the mixture perfectly uniform. By this time a cart or a barrow has arrived from board G. Having discharged the contents of his board, mixer A finds that the gravel man from G has already filled his box, which he pulls over as before, and the whole cycle of operations is repeated. It is obvious that close supervision of such a system is very easy.

One of the most important results effected by the process is perfect mixing with very little water. The concrete is only so far wetted that when squeezed forcibly in the hands a slight dampness appears on the surface. So small is the quantity of water used, that many persons accustomed to concrete mixing have remarked that the mortar will not set properly without more water. Concrete formed with mortar of this consistency can be beaten into a much more compact mass than when a larger proportion of water is used; it is much stronger, and can be formed to a more accurate figure at the surface.

In the earlier trials of this work in Liverpool, the concrete mixing was performed in the street. A carriageway, running for example north and south, having been closed, the excavation, commenced at the north end was proceeded with, at first by carting both northwards and southwards. When a sufficient opening was made the concreting was commenced at the northern end, the mixers being placed south of the concrete, and the materials for concrete south of the mixers. As the concreting progressed, the mixers were moved southwards. It was found to be impossible to mix so much concrete within the limits of the carriageway as could be laid *in*

situ in the same time, and the work was much impeded by the limited space.

In order to ascertain whether any mode of mixing at a short distance from the site could be devised which would not diminish the strength of the concrete owing to subsequent disturbance in laying, the Author tested carefully prepared samples of concrete, some moulded immediately after mixing, and others moulded, and thus disturbed, at different periods after mixing. In a modified degree the results had been anticipated; but the incorrectness of the prevalent opinion as to the effect of remixing was shown to be much greater than was expected, so far at least as concrete made with good slow-setting Portland cement was concerned.

A summary of the results of four hundred and eighteen experiments, both in compression and tension, which determine this question, are given in the following table (page 13).

Since the time when the first set of these experiments was made, concrete mixing in the street for which the concrete is destined has been abandoned, and any convenient yard or other place has been used, from which the concrete may be deposited within a moderate time after mixing. In the Author's opinion, the change has not diminished the strength of the concrete.

It is well known that fresh Portland cement is unfit for use, on account of the large quantity of uncombined lime it contains. If moulded in this condition the lime slakes while the cement is setting, and often breaks it up completely. To avoid this the cement must be thoroughly purged, that is, exposed to the atmosphere for a considerable time. By this means the lime is slaked to a sufficient extent to prevent any failure of the work from subsequent slaking. This action diminishes as the purging becomes more complete; but even in the best Portland cement after exposure to the air for an indefinite time there is rarely a diminution, though there is sometimes an increase of strength if allowed to stand fifteen or twenty minutes between the process of mixing and placing *in situ*. It is difficult to ascribe any cause for this, except on the hypothesis that even in the best purged cement there remain minute points of compression, scattered throughout the mass, and produced by minute particles of lime, which are slaked on the application of water. Whether or not this be the true explanation, the facts are indisputable, and have an important bearing upon many works in concrete.

The cost per superficial yard of Portland cement concrete

AVERAGES of 418 TESTS of PORTLAND CEMENT and PORTLAND CEMENT CONCRETE, PLACED IN SITU at VARIOUS INTERVALS of TIME AFTER MIXING.

Number of Minutes between Mixing and Moulding	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
Means of crushing strengths of 24 blocks, 5 parts river gravel, 1 part cement; 1 cube foot each; tested 26 and 28 days after moulding. Tons per square foot	45·55	..	..	..	49·00	>50·00[1]	..	48·58	..	47·07	..	45·15													
Ditto, ditto; 24 and 28 days after moulding. Tons per square foot	49·57	..	..	..	..	>50·00[1]	..	..>50·00[1]	..	..	47·56	..	46·55	..	..	..	43·55								
Means of tensile strengths of 240 2¼-square-inch sections of pure cement, and Oporto gravel and cement varying from 1 to 1 to 4 to 1; pure cement tested 7 days, concrete 14 days, after moulding. Lbs. per 2¼-square-inches	..	602	579	571	604	593	599	594	609	523	498	567	507												
Means of tensile strengths of 144 2¼-square-inch sections of pure cement, and Oporto gravel and cement varying from 1 to 1 to 5 to 1; pure cement tested 7 days, concrete 14 days, after moulding. Lbs. per 2¼-square-inches	..	..	593	..	590	..	581	..	578	..	580	..	588	..	581	..	562	..	544	..	566	..	560	..	524

[1] 50 tons was the greatest compression capable of being applied by the machine employed.

foundations in Liverpool, 6 inches deep, constructed in the manner above described, is as follows:

		s.	d.
0·132 ton	Broken stones, including cartage, at 6*s.* . .	0	9·5
0·174 „	River Dee gravel „ „ „ 5*s.* 6*d.* . .	0	11·5
0·024 „	Portland cement „ „ „ 52*s.* . .	1	3
	Labour, mixing concrete	0	3·25
	„ laying *in situ*, beating, and shaping .	0	2·75
		3	6
	Add for establishment expenses, 8 per cent. . .	0	3
	Total per square yard	3	9

Bituminous Concrete Foundations.—The positions in which bituminous is preferred to cement concrete, have already been described. It is constructed in Liverpool as follows: On the hard but often irregular bed of the old foundation, previously well brushed, is thrown the required thickness of broken stone of the size of rough macadam. This is well levelled and rolled to the proper form, and over it is poured precisely the same asphaltic composition as that above described for making the joints of sets. The asphalt sinks to the bottom, and fills the smallest crevices between the stones. On the surface, while the asphalt is still warm, is laid a thin stratum of small broken stone, which is thoroughly rolled into the asphalt, and fills up the upper spaces between the larger stones. As in the process of rolling the soft asphalt rises between the smaller stones, still smaller riddlings are scattered over it, until a perfectly true and uniform surface is obtained. In a few hours this surface will bear any amount of ramming without distortion.

The cost per square yard of bituminous concrete foundations in Liverpool, 6 inches deep, is as follows:

		s.	d.
0·153 ton	Broken stones, including cartage, at 6*s.* . .	0	11
0·041 „	Pitch „ „ „ 30*s.* . .	1	3
1·2 gallon	Oil „ „ „ 2½*d.* . .	0	3
0·007 ton	Coke „ „ „ 12*s.* . .	0	1
	Labour	0	9
		3	3
	Add for establishment expenses, 8 per cent. . .	0	3
	Total per square yard	3	6

Carriageways of Bituminous Concrete, or Asphalt Macadam.

A pavement may be constructed precisely in the same manner as the bituminous concrete foundations above described. It is absolutely impervious to moisture, and in first cost less expensive, though by no means so durable as a stone pavement, or as a rock-asphalt pavement; but, nevertheless, it is sufficiently durable for the numerous back streets of a great town, in which facility of cleansing is of primary importance.

In constructing such pavements it is desirable that the upper layer of large stones should be of smaller size than is necessary for concrete, and that they should not be harder than limestone. The still smaller stones and riddlings should be similarly limited in hardness. The object of this proviso is that the asphalt between the stones may not wear down much more rapidly than the stones, and thus leave in time an uneven surface. The proper consistency of the asphalt is of even more importance than when it is simply used for joints. About 23,000 square yards have been laid in Liverpool, and on sanitary grounds the system will probably be extended annually over large numbers of back streets.

The cost per superficial yard of bituminous concrete pavements 6 inches deep, as constructed in Liverpool, is as follows:

		s.	d.
0·144 ton	Broken stone and limestone chippings, including cartage, at 7s. 6d.	1	1
0·041 ton	Pitch, including cartage, at 30s.	1	3
1·2 gallon	Oil " " " 2½d.	0	3
0·007 ton	Coke " " " 12s.	0	1
	Labour	0	10
		3	6
	Add for establishment expenses, 8 per cent.	0	3
	Total per square yard	3	9

Bituminous concrete is usually prepared in other places by pouring coal tar over broken stones of the size of macadam and previously heated. The stones are then laid, and thoroughly rolled to the contour of the finished surface; after which about an inch of similarly prepared chippings, by preference limestone, is spread upon them and thoroughly rolled.

The Author tried this method in Liverpool, but subsequently obtained greater success by the first method described. In some Lancashire towns where the second method is employed, the surfaces appear generally to become disintegrated more

readily than those in Liverpool. Recently, however, he has examined some street carriageways laid in Derby by Mr. Clement Dunscombe, according to the second method, and they are among the best artificial asphalt pavements he has seen. As creosote oil cannot readily be obtained in all towns, and as tar can be obtained wherever gasworks exist, a knowledge of the details of Mr. Dunscombe's practice and experience would be of great service to the surveyors of provincial towns, even if it does not supersede the first method where creosote oil is cheap.

Wood Pavements.

In Great Howard Street, Liverpool, where the traffic exceeds 3,300,000 tons annually, or 216,000 tons per yard width of carriageway, one of the most important hospitals in Liverpool is situated. Near all hospitals it is of course desirable to reduce the noise to a minimum. At first this was done by the use of macadam in the middle half of the carriageway; but the difficulty of maintaining it became so great, that in 1871 a set pavement was laid. In 1872 the Author recommended the substitution of timber. The northern half of the work, about 700 square yards, was accordingly paved in 1873 by the Improved Wood Pavement Company. The site having been excavated and levelled, boards of Baltic pine, 1¼ inch thick, were laid diagonally upon 3 inches of sand, and upon these a second layer of similar boards was spiked. The blocks of wood were of Baltic pine, 6 inches deep, 7 inches and 8 inches long, and 3 inches wide. The ends were placed in contact, and a space of ¾ inch was maintained between each row by a narrow strip of wood nailed to the planking. This space was subsequently caulked with gravel and a bituminous composition. The whole surface was finished with a coating of asphalt and gravel. This work was subject to very frequent repair, and was entirely relaid after four years' use. The defects were due chiefly to the absence of a proper foundation, for though the blocks had worn down from 2 to 2½ inches during the four years, they would, if properly held in position, have lasted some time longer. The Author declined to recommend the further trial of wood in this place unless laid upon a good bed of concrete. Accordingly, in 1877, a pavement, the surface of which was similar to that employed in the first instance, was laid upon a bed of bituminous concrete, constructed as already described, and underlying the plank foundation.

The southern half of the work, about 700 square yards, was also laid in 1873, by different contractors, on a material which was dignified with the name of concrete. The blocks were of Baltic pine,

grouted with Portland cement mortar, a material quite unsuited for use in combination with wood. Notwithstanding the consolidating action to which for years the ground had been subjected, the lines of heaviest traffic soon showed signs of sinking, while the adjoining blocks were pressed upwards; and after ten months' use the pavement became dangerous, and was entirely relaid on the same system, at the contractors' risk. This pavement had to be removed in twelve months, when a wood pavement similar to that originally laid on the northern half was substituted. The pavement shows very plainly the want of a concrete foundation.

In 1874 the pavement of Bold Street, 4,250 superficial yards, was laid by the Improved Wood Pavement Company, in a manner precisely similar to the northern half of the Great Howard Street work. It is a shop street, with a traffic consisting chiefly of carriages, amounting to about 94,000 tons per annum per yard in width; but even here the want of a concrete foundation soon became manifest, though on the whole the pavement has worn, with moderate uniformity, to the extent of about $\frac{5}{8}$ of an inch in four years.

When it became desirable to continue wood pavement along the upper part of Church Street, the Author accordingly recommended a bituminous concrete foundation, 3½ inches thick, which was laid under his direction in 1878. Upon this the Henson Street Paving Company laid their pavement, which consisted simply of pine blocks from Soroka, 3 inches by 6 inches by 9 inches long, separated only by a single thickness of tarred felt, a layer of which was also placed between the foundation and the blocks. A transverse V groove, 1 inch wide, was cut by the contractors in a row of blocks at every 12 inches, ostensibly with the object of preventing horses from slipping. Owing no doubt to the nature of the foundation, this pavement has retained its original form better than any wood pavement the Author has seen.

The Author has not hitherto required the surface blocks of wood pavement to be creosoted, but they have always been selected with the greatest care. The foundation boards when used have been creosoted with not less than 10 lbs. per cubic foot.

In order to maintain a wood pavement in good condition it is necessary to scatter fine sharp siliceous gravel over it from time to time. This operation adds considerably to the cost of maintenance, but, if properly done, it prevents slipperiness; and if not overdone, the little angular pieces become so firmly embedded in the fibres of the wood that they are prevented from rolling, and are gradually worn away on one side only.

The first costs of the wood pavements most recently laid in Liverpool have been as follows:

Cost of Wood Pavements per superficial yard.

	s.	d.
Improved wood pavement, as laid in Great Howard Street, in 1877, including double plank foundation	16	0
Improved wood pavement, as laid in Bold Street, including double plank foundation	15	3
Henson's wood pavement, as laid in Church Street, including bituminous concrete foundation 3½ inches deep .	15	10

It is scarcely just to wood pavement, however, to compare these figures with those previously given for other classes of pavement. In the case of the wood pavements, the work was executed by London companies; in the case of the other pavements, by the workmen of the Corporation; and the 8 per cent. allowed in the latter case for establishment expenses, would inadequately represent the additional cost necessarily involved in the contract work.

With Liverpool prices at the present time, the actual cost per square yard of wood pavement, with blocks 6 inches deep and bituminous concrete foundation, would be as follows:

	s.	d.
Bituminous concrete	2	0
Creosoted Baltic pine blocks, pitch grouting, and gravel, including labour	12	0
	14	0
Add for establishment expenses, 8 per cent.	1	1½
Total	15	1½

Macadamised Carriageways.

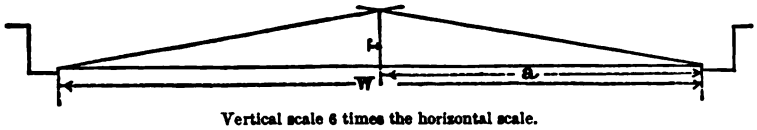
There are no thoroughfares near the centre of Liverpool, and but few in the outskirts, which are still paved with macadam. The cost of maintaining macadamised carriageways where the traffic is great is so much in excess of the cost of maintaining set pavements; the dirt in wet weather, and the dust in dry weather, are so objectionable; and the quantity of detritus washed from them into the sewers is so large, that for many years they have been abandoned except for a few leading carriage thoroughfares to the outskirts. The proper construction of the substratum of macadamised roads is well known, but not always followed. Much difference of opinion exists, however, as to the best mode of finishing or blinding the surface. The Author has tried many methods. Under a 15-ton steam roller, preceded by a watering cart, 1,200 yards of trap-rock macadam, without blinding, can only be moderately consolidated by twenty-seven hours' continuous rolling.

If blinded with hard rock chippings from a stone breaker the same area may be moderately consolidated by the same roller in eighteen hours. If blinded with siliceous gravel from $\frac{3}{4}$ inch to the size of a pin's head, mixed with about one-fourth part of macadam sweepings obtained in wet weather, the area may be thoroughly consolidated in nine hours. Macadam laid according to the last method wears better than that laid by the second, and that laid by the second much better than that laid by the first.

Contour of Cross-Section.

For the purposes of traffic, and traffic alone, the best form of cross-section for a carriageway would be a level line, as any cross-fall produces friction, additional traction, and wear and tear of horse and vehicle. But for the rapid discharge of rainfall a cross-fall is necessary. The problem is therefore to design the section in such a manner that the water shall be properly discharged with the least possible maximum fall. Suppose the least desirable inclination to be known, if this were adopted as the maximum inclination also, the profile shown with an exaggerated vertical scale in Fig. 1 would be obtained. This profile would be

Fig. 1.

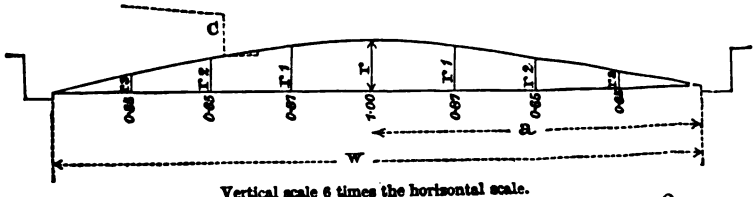


Vertical scale 6 times the horizontal scale.

objectionable on the ground of appearance, and because the breasting would tend to wear hollow.

Having due regard, however, to these considerations, the figure should approximate as nearly as possible to two straight lines, meeting at the vertex of the carriageway. If the vertex is slightly rounded, and the breasting still more slightly rounded, a profile is obtained approximating to a hyperbola, as in Fig. 2,

Fig. 2.



Vertical scale 6 times the horizontal scale.

and differing widely from the segment of a circle too often adopted, in which the crown is very level and the breasting unnecessarily inclined.

Let a = the horizontal distance from the vertex to the lowest channel in feet.

Let r = the rise of the vertex above the lowest channel in feet.

„ d = the difference of the levels of the two channels in feet.

„ w = the width between the channels in feet.

For well made impervious pavements

$$r = \frac{a}{36}$$

When there is a cross-fall from channel to channel, the crown or vertex of the pavement is generally placed too near the centre, and an unnecessary fall on the lower side is involved. In order that the inclination of the pavement on the two sides of the vertex may be the same, it is necessary to include only that portion of the curve in Fig. 2 which lies between the two channels, when the upper channel is placed in such a position c that the known ratio $\frac{w}{d}$ is maintained. If $\frac{w}{d} = 36$, the figure of the carriageway is half the above figure. If $\frac{w}{d}$ is greater than 36, the figure of the carriageway is greater than one-half of the above figure, and the fall is towards both channels. If $\frac{w}{d}$ is less than 36, the figure is less than half the above figure, and the fall is wholly towards the lower channel.

The height r_1 above the chord line, of a point at the distance $\frac{a}{4}$ from the vertex, should be $0{\cdot}87\ r$.

The height r_2 above the chord line, of a point at the distance $\frac{a}{2}$ from the vertex, should be $0{\cdot}65\ r$.

The height r_3 above the chord line, of a point at the distance $\frac{3a}{4}$ from the vertex, should be $0{\cdot}35\ r$.

In order to apply these deductions to practice the curve in Fig. 2 should be drawn to a large scale for reference. For pavements without cross-fall the full curve is to be included. For pavements with cross-fall the upper channel c is to be so placed on the curve that $\frac{w}{d}$ in the street is equal to $\frac{w}{d}$ in the figure, and only

the portion of the curve between *c* and the lower channel is to be taken.

It is thus a very simple matter to set out the cross-section of any pavement to the proper curve, when the width between the channels and the difference of their levels are known; and if, in fixing the heights, foremen were always instructed to follow such simple rules, the minimum friction arising from lateral pressure in vehicles, consistent with proper water-discharging power of the pavement, would be attained. The fact that these objects are not always sought must be the Author's excuse for bringing such simple matters before the Institution.

Having so designed the cross-section of a carriageway, that without unduly increasing the traction, and wear and tear of vehicles owing to lateral pressure, water runs from it to the channels with maximum efficiency, it is important to consider the best mode of conveying that water to the sewer gullies. The best channels are heavy blocks of hard rock 12 to 18 inches wide, with at least one natural and perfectly smooth face. The slabs should be set upon concrete, with close dressed joints filled with asphalt, and with a fall of $\frac{1}{4}$ inch per foot towards the curb, and not, as is sometimes done, with the same, comparatively great fall, as the breasting of the pavement, which tends to throw the wheels of vehicles against the curb. The lower edge of the pavement should be about $\frac{3}{8}$ inch higher than the upper edge of the channel. If constructed in this manner a longitudinal fall of 1 in 200 is sufficient to discharge the water rapidly.

II. Comparative Advantages of various Classes of Pavements.

Much has from time to time been written on the relative advantages of various classes of pavements; but the elements necessary to make the statements comparable have always, so far as the Author is aware, been absent. Light traffic, and much oftener heavy traffic, is spoken of; but the heavy traffic is often so called because a few times in the year a heavy boiler or piece of machinery is drawn over it; and, in another case, because the carriageway is crowded with Hansom cabs and other light vehicles. The Author has endeavoured to formulate the question in such a manner that the results may be generally applied.

With reference to the traffic, the knowledge of three easily ascertained facts is necessary:

(*a*) The tonnage passing over the carriageway in twelve months.

(*b*) The width of the carriageway.

(*c*) The number of wheels on which the twelve months' traffic is borne.

Then $\frac{a}{b}$ = the weight of traffic per yard of width, and $\frac{a}{c}$ = the number of tons per wheel, giving a fair relative knowledge of the average kind of traffic in various streets.

With respect to the wear of a pavement, the following course should be adopted. If stone sets are in question, one or two rows of sets, the full width of the carriageway, should be taken up and weighed. They should then be carefully replaced, so as to be perfectly flush with the surrounding pavement, and at the end of twelve months again weighed. If the material is wood the exact measurement of a number of sets is sufficient. In addition to the information thus obtained, a street ledger should be kept, giving at a glance the cost per square yard of maintaining every pavement for each year. If, in writing of the relative durability of various pavements, this information were given, an immense amount of experience might be rendered generally available. Without some such information, any statements made can be little more than the opinion of individuals based upon impressions with respect to the traffic, which are by no means always correct.

About 300,000 square yards of stone pavement, constructed as described at pages 2 to 9, have been laid within the last six years, in streets of varying traffic in Liverpool, up to 360,000 tons per yard width per annum, and an average of 0·923 of a ton per wheel including empties—two figures which, taken together, are probably not surpassed, if indeed they are equalled, by any other traffic in the world.[1]

The old pavements in streets of such traffic were generally of the hardest and most durable stone (A and B in the Table page 4), and the foundations, as already stated, of hand pitching; nevertheless, the pavements cost about 3*d.* per square yard per annum to maintain, and they were never in good condition. The hard stone sets B and C, paved on concrete, and with impervious joints, remain in excellent condition. The oldest of these pavements, constructed in 1872, though subjected to a traffic of 218,000 tons per annum per yard of width, and a mean load of 0·679 ton per wheel including empties, have hitherto cost nothing to maintain beyond the occasional filling up of joints with asphalt, and the restoring

[1] The traffic given is that in the dock line of streets. In the average load of 0·923 ton per wheel, empties and light traffic are included.

of a few sets, not worn, but split and crushed by loads of 60 tons on four wheels.

The rate of wear under the greatest traffic has not exceeded 0·02 of an inch of solid stone per annum, except at junctions of streets and some other places, where very hard stones were avoided in order to prevent slipperiness.

Under a smaller traffic the macadam opposite the hospital in Great Howard Street cost 3*s.* 6*d.* per yard per annum to maintain, and would now cost 4*s.* 8*d.*; and in the same place wood costs the Corporation, including gravelling, 1*s.* 11*d.* per annum to maintain. The greater part of this is, however, paid to the Company for maintenance, and really therefore includes a sinking fund.

These figures serve to show generally the great divergence in the cost of maintenance; but they do not include cleansing, the figures relating to which are still more favourable to the asphalt-jointed pavements. But a much more correct idea of the total difference of cost may be gathered from the following table (see page 24), in which first cost, renewal, and maintenance are all duly considered.

If the standard of traffic be taken at 40,000 instead of 100,000 tons per annum for every yard in width of carriageway, the figures for the last three pavements are as follows:

Description of Pavement.	Original Cost per Square Yard at present Prices.	Deductions from First Cost to determine Cost of Renewal.		Interest on Original Cost at 4½ per Cent. per Square Yard per Annum.	Sinking Fund Invested at 3 per Cent. Compound Interest.	Maintenance per Square Yard per Annum.	Scavenging[1] per Square Yard per Annum.	Gravelling per Square Yard per Annum.	Total Annual Cost per Square Yard.
		Cost of Foundation not requiring Renewal.	Allowance for old Materials at Date of Renewal.						
	s. *d.*	*s.* *d.*	*s.* *d.*	*d.*	*d.*	*s.* *d.*	*d.*	*d.*	*s.* *d.*
No. 6. Bituminous concrete pavement .	3 9	Nil	Nil	2·0	Nil	0 9	2·4	..	1 1·4
No. 7. Wood pavement .	15 1·5	2 0	Nil	7·5	4·3	0 1·0	2·7	5·0	1 8·5
No. 8. Macadam pavement . . .	6 9	Nil	Nil	3·4	Nil	1 0	8·0	Nil	1 11·4

[1] For the figures relating to the cost of scavenging, the Author is indebted to Mr. R. S. Reynolds, M.R.C.V.S., who, as chief of the scavenging department in Liverpool, has given great attention to the subject.

While discussing the other comparative advantages of various classes of pavements, the total annual cost as shown by the foregoing Table should be borne in mind.

TABLE SHOWING the TOTAL COSTS of VARIOUS PAVEMENTS.

In this Table the cost of Maintenance and Scavenging are reduced to a standard traffic of 100,000 tons per annum for every yard in width of the carriageway. It is assumed that the work is done by the Corporation, and 8 per cent. of the cost of both labour and materials is included for establishment expenses.

Description of Pavement.	Original Cost per Square Yard at present Prices.	Deductions from First Cost to determine Cost of Renewal.		Interest on Original Cost at 4½ per Cent. per Square Yard per Annum.	Sinking Fund Invested at 3 per Cent. Compound Interest.	Maintenance per Square Yard per Annum.	Scavenging per Square Yard per Annum.	Gravelling per Square Yard per Annum.	Total Annual Cost per Square Yard.	Remarks.
		Cost of Foundation not requiring Renewal.	Allowance for old Materials at Date of Renewal.							
	s. *d.*	*s.* *d.*	*s.* *d.*	*d.*	*d.*	*s.* *d.*	*d.*	*d.*	*s.* *d.*	
No. 1. Sets 7½ inches deep. Class of stone A, B. Gravel joints. Hand-pitched foundation .	12 1	1 6	3 0	6·5	1·8	0 1·0	4·2	Nil	1 1·5	Old Liverpool pavements.
No. 2. Sets 7½ inches deep. Class of stone B, C, D, E, F. Asphalt joints. Portland cement concrete foundation . . .	15 1	3 9	3 0	8·2	0·6	0 0·25	2·4	Nil	0 11·45	Pavement now constructed in Liverpool for heavy traffic.
No. 3. Sets 7½ inches deep. Class of stone B, C, D, E, F. Asphalt joints. Bituminous concrete foundation	14 10	3 6	3 0	8·0	0·6	0 0·25	2·4	Nil	0 11·25	Ditto ditto.
No. 4. Sets 7½ inches deep. Class of stone G, H, J, K, L, M, N. Asphalt joints. Portland cement concrete foundation .	15 1	3 9	3 0	8·2	3·7	0 0·5	2·4	Nil	1 2·8	Pavement now constructed in Liverpool for light traffic, or steep gradients, and junctions of streets.
No. 5. Sets 7½ inches deep. Class of stone G, H, J, K, L, M, N. Asphalt joints. Bituminous concrete foundation . . .	14 10	3 6	3 0	8·0	3·7	0 0·5	2·4	Nil	1 2·6	Ditto ditto.
No. 6. Bituminous concrete pavement	3 9	Nil	Nil	2·0	Nil	1 6·0	2·4	Nil	1 10·4	Pavement recently employed in Liverpool for back streets, and for street carriageways of very light traffic.
No. 7. Wood pavement, blocks 6 inches deep Bituminous concrete foundation . . .	15 1·5	2 0	Nil	7·5	10·1	0 1·0	2·7	5 0	2 2·3	Creosoted wood pavement, if constructed by Corporation.
No. 8. Macadam pavement, hand-pitched foundation . .	6 9	Nil	Nil	3·4	Nil	2 0·0	8·0	Nil	2 11·4	Now only employed in Liverpool for suburban roads.

Pavement No. 1.—In this old form of Liverpool pavement the hard sets of the class A and B, when subjected to slow and heavy traffic, were invariably after a few years pushed from the vertical line, by the backward pressure of the horses' feet, through a considerable angle often as large as 25°. As the sets on the two sides of the street were pressed in opposite directions, a wave-line was assumed by each course. Instead of the whole upper surface of each set being duly presented to the wheels, each surface was therefore inclined, and the wear was confined chiefly to the upper edges. The effect of this in the production of noise may be readily conceived; but as such pavements, though cheaper in first cost, are shown by the foregoing table to be more expensive than the best class of hard stone pavements, Nos. 2 and 3, it is unnecessary to refer to them further.

Pavements Nos. 2 *and* 3.—These pavements are now exclusively employed for the straight lines of heavy traffic in Liverpool, where the gradients are moderate, and the sets maintain the positions in which they are originally placed. For some time after the asphalt has worn off the surface, the noise caused by traffic is considerable, and horses appear much more liable to slip than at subsequent periods. The noise is due to the irregularities of the surface; and the slipping, though on first thoughts it may appear anomalous, is due to the same cause.

Cæteris paribus, a horse is less liable to slip upon a level unpolished surface with narrow joints, 3 inches apart, than upon the irregular surface of new hard stone sets. This may be partly due to the greater traction and partly to the uncertainty with which the horse feels the ground. In the North John Street pavement, the first of the class in question laid in Liverpool, this fact has been very obvious. For the first year of its life the pavement was strongly objected to by the carters on account of the slipperiness; but in this, as in all other cases, the complaints ceased when the larger projections had worn off. Owing, however, to the original existence of those projections, and owing also to the fact that many arrises are unduly broken off, the sets do not wear to so uniform a level as they undoubtedly would if the upper surfaces were better formed in the first instance. With the harder trap rocks and syenites the Author believes that a more perfect pavement for heavy traffic than has yet been produced could be formed, if the upper surface of each set were roughly but uniformly dressed. The present method of wearing down the projections by the rolling contact of wheels in street traffic is certainly not an economical method; and if the smoothing were done at the quarries the objections which obtain to

the use of such sets in many places, owing to the noise, and liability to slipping which they at first cause, would be in a great measure removed. The time required to wear down such projections, when the sets are properly held in position, may be judged from the fact that in North John Street almost every other set still shows hollows which originally existed in the surface, and which the wear of a total traffic in six-and-half years of about 1,417,000 tons for every yard in width has not yet reached. The difficulty of sufficiently dressing one surface of such sets by hand is no doubt very great; but the design of a machine for the purpose is well worthy of attention. The problem must not be confounded with that involved in the dressing of any ordinary rock, even the hardest used in building, or even with that of dressing granite for paving purposes.

Pavements Nos. 4 *and* 5 have been employed in Liverpool for light quick traffic, or where the gradient is too great for pavements Nos. 2 and 3, and at the junctions of streets where, in turning corners, horses are more liable to slip. Each stone classed under this and the last head has its own peculiarities, which are explained, so far as possible, in the table at page 4. They all wear much more rapidly than those of the last class, but some of them, while absolutely free from slipperiness, wear flat, and retain their arrises. On this account they are remarkably suitable for quick traffic, and produce but little noise. The stones in this class wear so readily to a uniform surface, that it would not be worth while to dress their surfaces as is suggested in the last case.

Pavements Nos. 2 *to* 5 *inclusive* may be classed together with regard to cleanliness and traction. They are easily cleansed, and the result of a single sweeping is most satisfactory. They are remarkably free from dust in dry weather, and from mud in wet weather.

Some years ago, the Author considered the desirability of testing the traction on various pavements by a dynamometer; but subsequent observation convinced him that such a course would only give misleading results. The work capable of being performed by a horse in drawing a load is dependent, not only upon the absolute power required to move the load at a certain speed, but also, and in a high degree, upon the uniformity of the resistance, and upon the ease with which the horse travels—depending again upon the uniform roughness, if the term may be applied, without such irregularities as cause uncertainty in feeling the ground.

The Author decided, therefore, to draw his conclusions from a broader basis; and, fortunately, the actual increase of work performed on the new pavements is so great, that there is no difficulty

in doing this. It appears that in those lines of traffic in which pavements Nos. 2 to 5 inclusive have been substituted for pavement No. 1, the ordinary load of two horses has been increased by about 1 ton, and of one horse by about ½ ton. There is a general impression also that the speed even of the heavy cartage has been increased; if from no other cause, this is probably owing to the comparative absence of blocks in the traffic, for the speed of the quicker traffic is undoubtedly increased, and for a given traffic any given area of pavement is less crowded than before. The cost of maintaining vehicles is also stated to have been much reduced. It is difficult, however, to arrive at any absolute figures for the saving in wear and tear of horses and carts; but from the above data, taking the actual cartage rate of 1*s.* 6*d.* per ton, there is a saving in cost of cartage alone exceeding £10,000 a year for every mile of such a pavement as is now laid in the dock line of streets in Liverpool. This estimate can only be approximate; but the Author is satisfied that if the wear and tear of horses and carts could be included, the £10,000 per mile would be found to be considerably less than the actual measure of the benefit, apart from cleanliness and reduction of noise and cost of maintenance, which the public derive from comparatively perfect pavements. In the streets of quick traffic the actual loads conveyed may not be greater, but there is certainly a reduction in the wear and tear of horses and vehicles, and an increase of speed.

The Author has in this Paper devoted much attention to the consideration of pavements for streets of heavy traffic, as he is satisfied that in most of the great forwarding towns such pavements have received too little attention. It is no uncommon thing to find in the heart of the heaviest traffic of large towns, both in this country and abroad, pavements constructed of boulders, or of sets so indifferently laid as to move under every passing wheel. The older pavements of Liverpool were indeed excellent as compared with many elsewhere. If the authorities of such towns took a broad view of the subject, they would at once see the great loss to the trade of the country in general, and of their own towns in particular, which the continuance of such pavements causes.

In connection with pavements for heavy traffic, the use of stone tramways,[1] such as those employed on London Bridge, has often been advocated. With the pavement No. 1, as formerly constructed in Liverpool, tramways of perfectly smooth Penmaenmawr rock have

[1] Called in some towns "wheelers," with as much reason as stones to be broken for macadam are called "breakers."

been largely used. The stones were 12 to 18 inches wide, and were appreciated by the carters; though, owing to the limited width of the carriageways, the number of standing carts, and the varying rates of the vehicles, constant diversions from the line took place. This inconvenience is not, of course, felt to the same extent on a bridge.

When the impervious asphalt-jointed pavements were introduced, stone tramways were in some cases again employed; but it soon became obvious that they were no longer appreciated; and it was by no means uncommon to see the horse walking on the tramway stones drawing a load with wheels on the sets. The difference in traction was, in short, no longer perceptible. Replies to inquiries made of the Liverpool Cartowners' Association, and other large carriers, have supported this view, and tramways have been discontinued in all ordinary cases. Stone tramways are the outcome of defective pavements. Under heavy traffic they are exceedingly difficult to maintain in a stable position. They induce exceptional traffic on the sets adjoining them, and therefore cause grooves to be formed. In crowded streets, even on bad pavements, their utility is but slight; while on good pavements they are worse than useless.

Pavement No. 6, of bituminous concrete, is shown by the table to cost ultimately 1*s.* 10·4*d.* per yard for a traffic of 100,000 tons per yard of width. This is considerably more than stone set pavements, when laid in the best manner. It is not, however, suitable for streets of greater traffic than about 40,000 tons per yard of width per annum; and in such a street the annual cost of maintenance of bituminous concrete is so much more reduced than that of the stone pavements, that the prices become about equal, as is shown by the second table (see page 23), where the standard traffic is taken at 40,000 tons per yard of width per annum. In every town, whether great or small, there are many streets of dwelling-houses through which only the local traffic passes, and for such cases this pavement is admirably adapted. Wheels make as little noise upon it as upon rock asphalt, and horses' shoes make less; while it is moderately easy to cleanse.

Rock Asphalt Pavements.—In 1871 the Author investigated the subject of the Val de Travers and other rock asphalts. If it had been possible to adopt asphalt pavements for any considerable section of the Liverpool streets, there can be little doubt that the system would have been commenced. Moderately level streets exist in Liverpool running north and south, but nearly all those running east and west have inclinations, upon which such pave-

ments would be undesirable. Rock asphalt pavements have therefore not even been tried in Liverpool. It is to be hoped, however, that the experience of metropolitan engineers will enable a comparison between rock asphalt and other pavements to be made in the course of the discussion on this Paper, on the principle adopted in the Tables on pages 23 and 24.

No. 7, *Wood Pavement.*—To a number of energetic companies the successful introduction of wood pavement into this country is due. The stimulus given by the existence, or, in some cases, the fancied existence of several patents has initiated a work which, under other circumstances, would probably have been long delayed. Beyond a keen and useful competition, however, the patented inventions have not, as a rule, produced any special advantages, and the best forms of wood pavement are now probably open to any one to construct. This being the case, the Author has at pages 23 and 24 taken the cost of wood pavements, if constructed like the stone pavements of Liverpool by the Corporation. Even under these conditions it is clear that wood pavements must be regarded as luxuries when compared with the best stone pavements, though for traffics approaching or exceeding 40,000 tons per yard of width per annum they are less costly than macadam. Wood pavement, however, has not, in the Author's opinion, been yet constructed in the best manner. When first introduced into this country, it was thought necessary to provide foot-hold for horses by keeping the blocks from ½ an inch to 1 inch apart. The consequence was, that the fibres being spread by the traffic, absorbed impurities and wore away unduly. Experience has shown, however, that a close-jointed wood pavement, properly gravelled, is not more slippery than a wide-jointed wood pavement also properly gravelled. In the former the fibres cannot spread, and the little grains of quartz are much more firmly held in position than in the latter. Nor does it appear that creosoting makes the blocks when properly gravelled more slippery.

Wood pavements having wide joints, or imperfectly laid upon yielding foundations, have properly been objected to on sanitary grounds; but between these and close-jointed pavements upon concrete foundations there is a wide distinction; and although creosote is of little use where the fibres are liable to spread, it would greatly diminish absorption if applied to the extent of 12 to 14 lbs. per cubic foot, where the joints are close and where the fibres cannot spread. Under the most favourable conditions, however, wood pavement cannot be so efficiently washed, or otherwise cleansed, as asphalt-jointed sets, or rock asphalt, though

in this as in all other respects it is to be preferred to ordinary gravel-jointed stone-set pavements or macadam.

No. 8, *Macadamised Carriageways.*—Of all pavements macadam appears to the Author the least satisfactory for street carriageways in which the traffic exceeds about 30,000 tons per yard of width per annum. It is the most costly, the dirtiest, and, on the average of all kinds of weather and all conditions of repair, probably involves a greater traction for a given load than any of the other systems when thoroughly well laid. Its dirtiness consists, not only in the excessive mud of wet weather, and the excessive and impure dust of dry weather, but also in the facility with which organic impurities are absorbed by it, decomposed within it, and exhaled to the atmosphere. In country, and in some suburban roads the extent of this objection is insignificant, and no other pavement is better than well maintained macadam; but in some of the carriageways of the west end of London one would regard it as intolerable, had it not been tolerated so long. To the unsophisticated provincial the manner in which, on a hot July day, fashionable London rolls over her tainted macadam pavements, apparently without even smelling them, is a mystery almost as great as surrounds the fact that the metropolis, alone among the great centres of civilisation in this country if not in the world, still submits with apparent satisfaction to an intermittent water supply, impure at times in almost every household, however pure the source of that supply may be, when with absolute pecuniary benefit a constant supply might be obtained.

No. 1,635. "Wood as a Paving Material under Heavy Traffic."[1]
By OSBERT HENRY HOWARTH, Assoc. M. Inst. C.E.

THE long-standing problem which presents itself to those in whose province it lies, to provide and maintain in the principal centres of trade a roadway structure fulfilling the various requirements of modern street traffic, is one which often seems to be in effect scarcely less complex than any which the general practice of engineering has to deal with. There is certainly no other in which at the present time technical authority is so widely claimed in consequence of its importance to every separate local administration. The task of disentangling experiences from opinions, of verifying facts, and of purifying these from the bias of prejudice or interest, is too often sufficient to compromise the broad lines of general principle which can usually be established in such an inquiry. With due care, however, to discard all matters not relevant to the purely practical question, it is not difficult to show that the pith of it is comprehended in a very few facts. It is, indeed, this freedom of the problem from special technicality, and its consequent cosmopolitan handling, which still tend to apparent complexity, and to the perpetuation of the so-called "Battle of the Pavements."

The primary point into which these conflicting details can usually be resolved is simply this: That the conditions of road-surface demanded by the two main elements of street traffic, viz., the power and the load, are almost essentially opposed. That is, that the nature of surface most favourable to the intermittent tractive action of horses is not that which is best adapted to the transmission of rolling load. To reconcile these conditions, so far as to render them in the least degree obstructive to each other, is the practical aim of road paving.

It is of course assumed that the description of traffic to which the following remarks apply is that resulting from the concentrated activity of large commercial centres; and to meet which the costs of maintenance and of renewal have commenced to bear an important relation to the resources applicable to them.

It is to be noted in the first place, that the effects of wear and

[1] The discussion upon this Paper was taken together with that upon the one preceding.

tear on a roadway are developed in a variety of forms—pressure, percussion, abrasion, and external physical conditions—the relative proportions of which can scarcely be assigned with anything like distinctive accuracy in any case. But it is, notwithstanding, important in forming a correct conception of roadway wear and tear, to avoid giving undue prominence to any one of these destructive agencies. It is often observed, and with much reason, that the value of traffic observations, as regards paving, is qualified by the fact that no two streets in the world present identical conditions, and hence the futility of laying down a law as to pavement.

The series of observations, however, collected by the Author during the past three years, tend to show that against all the discrepancies which render comparisons of street traffic doubtful, opposite conditions are found to arise by which they are compensated in the long run; and that on the whole, the effect of such minor irregularities is, as might be expected, largely controlled by the element of weight. It is often assumed, on the one hand, that a generally low speed consequent on heavy loads is less destructive to a roadway than a light, rapid, and percussive traffic; and, as a point of opinion, the reverse is sometimes maintained. In this respect, however, compensation is proved to exist in actual crushing pressure and increased weight and effort of horses, as against more frequent and sudden pounding or tearing wear. Again, the central portions of a roadway are naturally considered to sustain the brunt of traffic as compared with that which passes to the sides; yet in five streets out of ten actually observed, this is fully compensated: first, by the fact that the sides of a roadway are subjected to the greater, though less continuous, wear of vehicles drawing up and pulling off again; and, secondly, by the fact that in all streets where the traffic is numerically such as to entail the preservation of an up and down line, a limited central section of such street is more or less protected, and subject to less wear and tear than the central portions of the two halves. And, lastly, it is claimed that, even assuming equivalents in weight, its direct effect is concerned in a much greater degree in a slow (because confined) traffic than in a free, fast, and, what may be called a jumping traffic. The answer to this objection is, that it rests upon the assumption of a bad road surface, and can therefore only apply in a constantly reduced degree as repairs and renewals tend to set it aside. The jumping action, which in a faster traffic takes the place of steady pressure, is due to inequality and obstructions of surface; whereas the moment a proper condition is restored, the conversion

of rolling pressure into a series of blows is not incidental to light more than to heavy traffic within any ordinary limits.

Upon such considerations it becomes evident, that the formula of direct weight per unit of roadway width is that which must afford the least erroneous datum for reducing large series of traffic observations taken under fixed rules respecting the conditions to be noted. The system adopted by the Author with this view furnishes the results shown in the Traffic Table A (page 48); and although the immediate source of these figures is a set of observations extending only over the month of November 1878, they represent, by correction with similar notes from other seasons and former years, a comparative scale which has not varied to any considerable extent within the six or seven years during which the resuscitation of wood pavements has become active. Indeed the figures of the appended Table B (indicating the general proportions of certain specific classes of London traffic) are of remarkable constancy, so far as any general comparison can be reached. The method adopted in taking them was aimed at obtaining reliable averages, by means of short and definite observations properly distributed, rather than from continuous counts over an isolated series of hours. The observations were therefore collected by half hours only, at fixed periods throughout the day of sixteen hours, from 7 A.M. to 11 P.M. in every case; such half hours being respectively observed again on different days at the same points and in different conditions of weather. The remaining night hours (11 P.M. to 7 A.M.) affording a traffic small in proportion, and at the same time subject to great irregularity with variable circumstances, were excluded as vitiating the averages required. The system of short observations, while undoubtedly leading to a highly corrected comparative figure, was also found to facilitate greatly the notes respecting weight, which were of necessity collected simultaneously with them. The traffic was divided under seven heads; for the most numerous and important of which the empty weights could be ascertained with precision, and the ordinary description of load estimated without any serious or cumulative error. Such as these averages are, they suffice to show how very widely the actual wear and tear upon any given roadway may be misconceived in the light of a merely general or numerical estimate. An instance of this is afforded by the figures of Table A, derived from twelve of the principal thoroughfares of the metropolis; amongst which the line of the Strand and Fleet Street, with the high traffic return of sixteen thousand two hundred and eight vehicles per day, yields a gross weight nearly the same as that of Gracechurch Street with

twelve thousand one hundred and forty-eight vehicles, the comparative weights per vehicle being as 0·8 ton against 1·1 ton; and the weights per wheel 0·25 ton against 0·37 ton. These results, again, are seen to be entirely modified by the factor of width; where Gracechurch Street stands far in excess, at 422·1 tons per foot; while Piccadilly and Leadenhall Street, with respectively ten thousand seven hundred and seventy-six vehicles against six thousand one hundred and twenty-eight, are identical at 253 tons of weight per foot. A difference, therefore, in actual wear of paved surface, which would scarcely be estimated at first sight, is thus made prominent; and it may be suggested that an established system of occasional short observations, combined of course with a careful record of maintenance costs, would supply by inexpensive means a statistical register, increasing in accuracy and value with every successive item. In such a record, also, due consideration might be given to exceptional loads of 5 tons and upwards, which have been purposely excluded from the table above referred to, on account of their comparative scarcity within a short period. It is probable that an addition of 10 per cent. all round to the weights there indicated would give a better approximation to actual facts.

Before any attempt can be made at a really comparative treatise on roadway wear under town traffics, the following points must clearly be conceded: (1) That no substantial evidence as to the actual economic work of pavements can possibly be acquired until some uniform system of recording experience has been adopted and generally adhered to; and (2) That such a system must include a record of cost based upon some equally uniform and accepted scale. The nature of street traffic, though admittedly in some respects much complicated, is not such as to render a record of this kind impracticable; and the question now being undoubtedly of sufficient importance to justify it, the result would be both to define the capabilities of any system of paving by the unit of ascertained wear, and at the same time to limit the controversial aspect of the subject.

In considering the circumstances which affect the durability of a road pavement (apart from traffic), these are found to be partly external to it, and partly dependent only upon material and construction. The former may be most briefly examined; and among them the variations of moisture are in all respects the foremost. Between the constant soakage of long-continued rains, or the retention of such water on the surface by the medium of mud, and the summer temperatures, when, on the other hand, the evaporative power is computed by hundreds of gallons per acre

per hour, a vast range of expansion, absorption, and other changes takes effect on the structure of a paved surface of large area. As to the manner in which these changes should be provided against in construction and material, opinion at the present time shows the widest possible divergence. Whether, on the one hand, the superstructure of a pavement should be such as to give exit to the water between itself and the foundation, or whether the entire mass should afford free drainage into the natural strata beneath; whether the material itself should retain a more or less variable proportion of the moisture, so as to be less susceptible of violent contraction and expansion, or whether, according to an opposite view, the whole water should be resisted by an absolutely impervious surface—all these are points constituting what is still a moot question. A minor effect, but an entirely distinct one (external to the pavement), is that of frost: and these two being the main external sources of injury, it is now a point of interest to inquire into their action upon fabrics of wood, as at present in use. According to the view of the Author, an indispensable feature of a weight-carrying pavement must be the absolute exclusion of water at the surface, as nearly as it can be ensured; and in this one respect it cannot be questioned that a surface like asphalt has no equal, the absorption being so gradual as to be inappreciable during any possible continuance of moisture. From this point the character of absorptiveness is presented in varying degrees by different materials and constructions down to the ordinary description of macadam paving, in which water becomes an essential ingredient of the roadway. A road of stone sets is of course impervious in material, but not often in structure; and intermediate between these are the semi-absorptive qualities of wood. The capacity of the common kinds of wood for absorbing water is exceedingly variable; and, as a rule, is much over-estimated, especially with reference to the amount of extraneous matter, soluble or otherwise, which can be conveyed into its fibres by the action of water.[1] Absorption, it must be remembered, takes place mainly by capillary action, and therefore only at such points as the fibre may be of capillary nature and easily separable—as in the lighter non-bituminous descriptions of wood, and the external, or unsound portions of its growth. And it is particularly worthy of note, that water is absorbed with far greater readiness in contact with a fibrous substance longitudinally, than by resting upon a transverse section of the same. In the one case every portion of fibre succes-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lvi., p. 300.

sively is free to displace itself in the act of expansion, and thus make way for the capillary action to extend inwards; while in the other, the whole area of fibre exposed end-wise must be more or less simultaneously expanded before absorption can proceed to any depth—a fact bearing directly on the conditions of wood in a pavement, and very commonly overlooked. Hence, in the particular instance of wood as usually disposed, with the fibre vertical under the action of traffic, absorption at the exposed end is in a great measure arrested, and should be intentionally arrested, by the choking of the fibres with foreign matter. If, in the first instance, the matter so becoming inlaid consists (as it should) of a clean, sharp, and hard grit, an important protection to the wood is gained by the exclusion of putrescent or other objectionable substances. This, as a question of structure, leads to the consideration of those conditions affecting the wear of a pavement which are referable to its own nature and qualities.

As observed before, the quality of absolute permeability to water is in almost every case open to serious objection, and, in that of a town roadway, inadmissible in the long run. No clearer evidence of this is afforded than the rapid formation of the large hollows and ridges occurring in a macadam road under high traffics; this being really due to the plastic condition in which the underlying material is constantly maintained. The substance of a macadam road is a conglomerate of broken stone and indurated clay—the latter formed by the infiltration of water and the detritus of the stone, which have previously been thoroughly worked up by the traffic. Even in a thickness of 12 or 15 inches, this conglomerate is not inelastic; and the formation of hollows having been immediately commenced by the movability of the fragments among themselves, it is further favoured (after they have become bound and consolidated) by the pliancy of the foundation. The Author is not aware whether the experiment has ever been made of laying a 12-inch macadam paving upon a concrete or other unyielding foundation—not, that is to say, a 12-inch thickness laid down *en masse*, and steam-rolled, so as to be instantly penetrable to pure water and frost, but formed by successive layers, consolidated under that regular action of traffic which cannot be imitated. Such a trial might probably be made to illustrate the facts of the case by two opposite results. Assuming, in the first case, that the surface were protected from the full effects of weather, and only watered sufficiently to preserve the best consistency, a far more durable roadway would in all likelihood be found to result from the support afforded by the foundation; whereas if, on the other

hand, the usual rainfall were allowed to act, the destruction of the road (as compared with the ordinary process) would be greatly hastened by the inability of the water to escape downwards, and the consequent effect of its remaining to soften, and, so to speak, dilute, the macadam.

Such being the theory of a road-surface, which, after the manner of macadam, is allowed to build itself, it is natural to inquire how the same effects are met by the systems on which roads are designedly built at the outset—a question comprising all the usual forms of paving for active traffic.

As regards built roads, much is generally said upon the question of elasticity, and it is one which is commonly misapprehended. Distinction is not made between two widely different theories, viz.:—Is road-elasticity requisite as it affects the traffic, or is it desirable as concerns the road itself? The answer is that, within limits, it is as advantageous to one as it is detrimental to the other. Elasticity of road is for the benefit of the traffic exclusively, and not for that of the road itself; and the inference is that, if any, it should be immediately at the surface, and there only. A totally inelastic road, whether absolutely smooth or designedly uneven, is open to objections, practically, on other grounds; and herein lies the chief characteristic which has brought wood into favour. Concurrently with a reasonable degree of durability, which admits of being used to the utmost advantage, it presents always, and uniformly, a slight degree of surface elasticity, to the immeasurable saving of vehicles passing over it.

The varieties of detail in the methods of constructing a roadway of wood have been exceedingly numerous; and to many of those of earlier date it is difficult to assign any purpose or principle except that of variety. The hexagonal and other sectional forms of block introduced into the first designs for wood paving are not less difficult to account for, from a practical point of view, than the still more elaborate varieties of conical, rhomboidal, or prismatic patterns which followed them, and the mere cost of shaping which, would, at the present time, entirely exclude them from employment on a large scale.

A type is shown in Fig. 1 of the class of block in which almost any form was aimed at except the rectangular, and the theory of which may be summed up in the fact, that the blocks were designed to withstand an assumed test which experience has shown to be mythical. The hexagonal block seems to have been employed so as to effect a close joint, with chamfered edges to afford foothold; but for what reason the chamfered edge of a rectangular block,

cross-cut from an ordinary deal, would not answer a similar purpose, does not appear. The rhomboid form has sometimes been supported on the ground that an inclined position of the grain is more favourable to wear than a directly vertical one; but such a theory is entirely untenable.

FIG. 1.

Scale $\frac{1}{12}$th full size.

Another totally groundless opinion, as regards wood blocks, was that which insisted on the necessity of something of the nature of a down-fastening. But the friction between the blocks, or the inserted material of the joint, and their natural hold upon each other and on their foundation, need never fall short of what is requisite to preserve the whole mass sufficiently immovable under any kind of traffic.

Much attention, again, has been devoted to the theory of a paved roadway being greatly enhanced in carrying-strength and stability by its being conceived to act as an arch. The Author has no hesitation in saying that the system of forces which constitutes a true arch-action could never be really brought into play in any roadway unless a material portion of the substratum were actually removed. The pressure caused by a loaded pair of wheels, or any number of wheels, on an ordinary paved street would, if carefully traced, be found to expend itself ultimately upon the underlying stratum of material only, and not, as in the case of an active arch, laterally upon the points which sustain it. The only conceivable instance in which such a principle could really apply (without an actual failure and breakage of the road) would be that of a narrow street in which the substance of the pavement was altogether without support from below. Moreover, in admitting the theory of arch-action, it must clearly be allowed that a rigid strength in the abutments—that is to say, in the kerb and foot-pavement which usually represent them—is as absolutely

indispensable as in the curve of the arch itself. As cases are well known to have occurred in which the expansion of the roadway, without any load, has sufficed to shift these from their position, it is scarcely necessary to go further to prove such a view to be fallacious.

Among the more recent types of construction, Figs. 2 to 4, one of the last to be modified as regards elasticity was that in which,

FIG. 2.

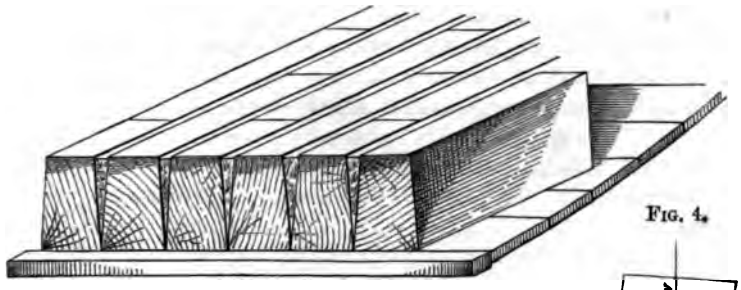


FIG. 4.

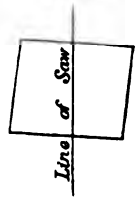
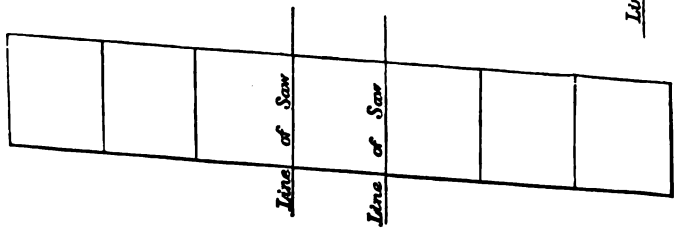


FIG. 3.



Clark's Wood Pavement. Scale $\frac{1}{12}$th full size.

as already observed, the necessary distinction failed to exist between the elasticity of the surface and the elasticity of the foundation. The system formerly adopted by the Improved Wood Paving Company (Fig. 5), was laid with a bearing of cross 1-inch battens (generally creosoted), either in single or double layer, under the blocks, without further foundation beyond the even contouring of the natural bed: but this has now given place to the use of concrete, with or without modification as regards the planking. The courses are spaced by a fillet of wood secured with brads, and the interval filled in with a composition of either bituminous or cement grouting.

In other systems, the interspace has been maintained either by wooden tenons and pegs, by iron stud-nails, by sheet iron, or merely by the filling itself. According to the principle of

FIG. 5.

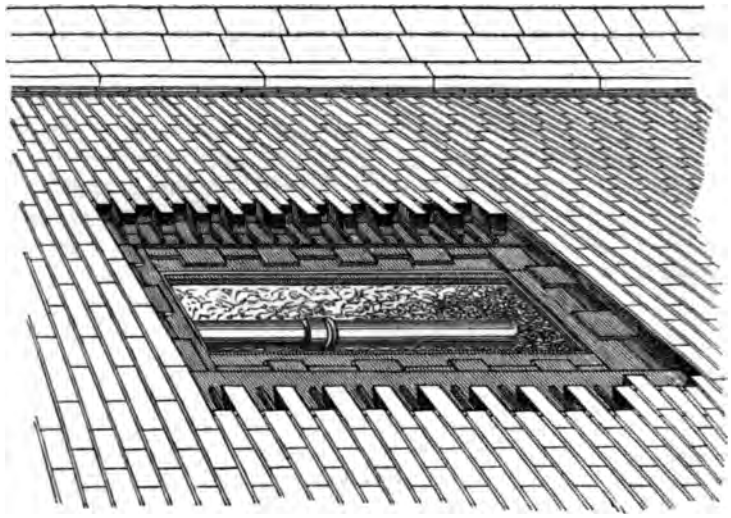
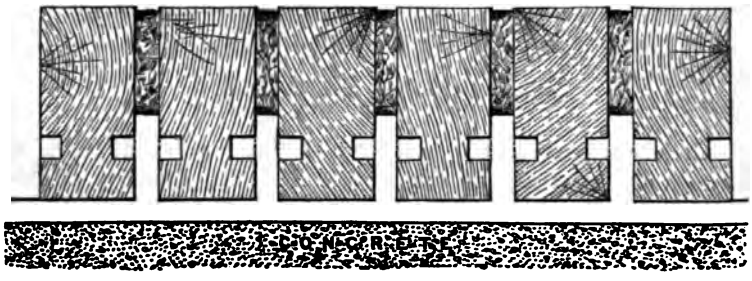


Fig. 6, the whole superstructure is designed to be keyed down by the use of a channel-groove or auger-holes in the sides of the blocks, such channel, as well as the interspace, being filled with

FIG. 6.



Method of uniting the blocks to the asphalt by auger-holes. Scale ¼th full size.

a material homogeneous with that upon which the blocks rest—whether bituminous or cement composition. This is brought to within a short distance of the surface, and the remaining depth is filled with the final surface-dressing of small ballast. The width of joint has been varied from 1 inch to ¼ inch or less, with

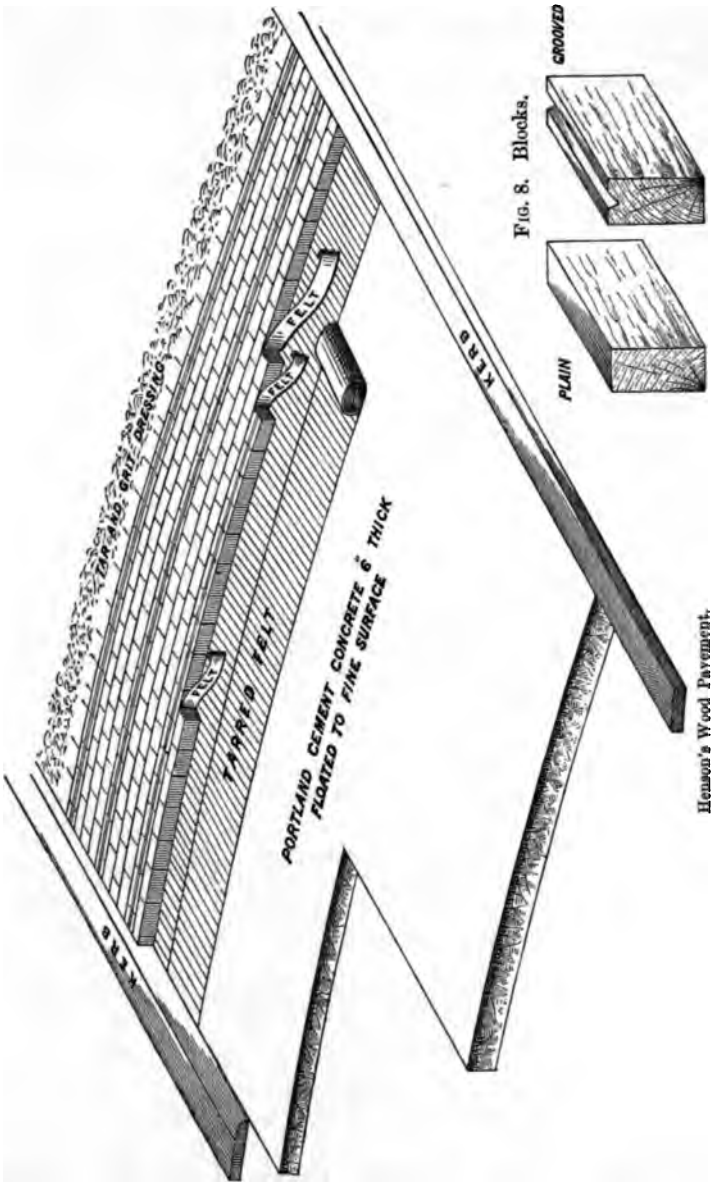
the result that the closer the joint the greater is the freedom of the pavement from mud; and the less permeable the interspace, the less is the amount of imported mud retained. The actual formation of mud upon a wood pavement, when once cleared of the residue of top-dressing first added, should be absolutely *nil*, as the detritus of the wood itself is too gradually formed to be appreciable. The removal of imported mud or dust, and the dressing with sand during frost, should comprise all the tending required. But in every instance of an open-jointed pavement, however varying in detail, the same results are to be noticed: (1) as to the wear of the blocks at the corners, and consequent opening of the fibres; and (2) the action of the interspace (whatever be the filling material) in eventually forming a superficial reservoir by which more or less mud and moisture are retained. If the filling of the interspace be not an impervious one, water and mud are retained between the blocks, in contact with the length of the fibre; and, if upon a solid foundation, without escape below. If the filling be of an impervious and rigid material, the courses of blocks are isolated from each other as regards expansive action; and on this account again, impermeability to water cannot be fully secured. The various experience afforded by these trials points to the conclusion, that the true theoretical condition under which wood should be used, is that of a continuous and uninterrupted surface. If a whole street could be conceived to be paved with a single slab or section of fir timber, the surface well inlaid with clean grit or large sand, such road would (apart from expansive action) present, without comparison, the fairest test of the durable qualities of this material.

Upon the basis of these principles the system of paving with wood known as Henson's (Figs. 7 and 8), was introduced in 1875, having for its object the testing of the previous theory, that artificial structural foothold is indispensable to afford a fulcrum for tractive power, as well as showing the value of real continuity of surface, by providing the nearest possible approach to an uninterrupted area of wood only.

It being sufficiently established by experiment, that the vertical position of the fibre was the only one in which wood could be employed so as to afford a durability comparing reasonably with that of stone, the simple and practicable form of blocks, cross cut to 5 or 6 inches depth from deals of the ordinary commercial dimensions, was not departed from; the most conveniently available being 3 inches by 8 or 9 inches. The aim of the experiment was primarily to lay the blocks "heart to heart," upon a sound weight-

bearing foundation, so as to present a continuous and uniform

FIG. 7.



surface of wood on end. To such a construction the only foreseen

obstacle was the variable expansion and contraction inseparable from that material under varying atmospheric conditions; and this, when accumulated over a large area, would doubtless have been of sufficient extent to become detrimental to the efficiency of a road pavement. With a view to meet this, it was borne in mind that the action of capillary expansion in wood is one which must be regarded as exercised slowly, through the minutest distances; but accumulated in proportion to the area of material subject to it. The compensation of such an expansion could therefore only be uniformly effected over a large area, by providing for the absorption of minute portions of it at the smallest possible intervals, establishing a series of minute compensations throughout the entire structure. Thus the accumulated horizontal expansion could only be taken up (without disturbing the whole mass) by an equivalent compensative elasticity distributed throughout it.

The substance which was found in practice to be most available for this purpose was the ordinary description of roofing-felt, from $\frac{1}{16}$ to $\frac{1}{8}$ inch thick; a strip of which, cut to the same width as the depth of the blocks, is interposed between each course, and thus forms a perfectly close and yet slightly elastic joint. In laying this pavement the system is adopted of driving up the blocks, as every eight or ten courses are laid, by means of heavy mallets and a plank laid along the face of the work, attention being given to the even range of the courses as this proceeds. The joint is thus closed as completely as possible, leaving only the actual fabric of the felt to take up the expansion, and, by the mutual support of the blocks, saving them from the rapidly destructive action of fraying down at the edges. The protection of the wood is farther enhanced by a continuous layer of similar or somewhat stouter felt over the whole surface of the concrete foundation, upon which the superstructure of wood is cushioned.

Results have tended to show, that the several functions of this simple construction were correctly anticipated. The endurance of the wood, consequent upon its relief from vertical jarring and the mutual support of the edges of the blocks, is increased by probably not less than one-half or two-thirds. Since the first experimental length upon this system was subjected to the traffic of Oxford Street, in the autumn of 1875, it has presented, without intermission, the appearance of a uniform and homogeneous surface, almost entirely free from detritus, and resembling that of asphalt.

In the earlier work, a V-shaped groove (Fig. 8) along the centre of the exposed end of the blocks was inserted at every fourth

course; but this serves very little real purpose as regards foothold, on the contrary, rather diminishes it, by becoming, like an open joint, a receptacle for mud, the true source of slipperiness. The use of the groove was therefore discontinued, except on inclines steeper than 1 in 30, or thereabouts.

A surface retaining the least possible quantity of extraneous matter is the desideratum; and only on this being attained can the true capacity of wood on end for affording a frictional foothold be duly appreciated. When this is increased by a dressing of clean sharp grit, or large sand, which at once becomes permanently inlaid into the fibre, it may be made amply sufficient to ensure the safety of all traffic under ordinary circumstances—even under the existing crude system upon which horses are shod. The Author exhibited two of the specimen blocks taken up recently from the centre of Oxford Street, where they have been subjected during three years and a half to a traffic of nearly 300 tons per foot per day. This figure, quoted from Table A, is of course not inclusive of the wear represented by the action of horses' hoofs, which, from its nature, can scarcely be estimated, but which, especially in the earlier part of the life of a pavement, bears the more important part in its wear. These blocks, originally 5 inches in depth, still show a surface inlaid with the particles of grit originally imbedded in it; and their actual vertical wear, allowing for a slight surface-compression, is almost inappreciable. From $\frac{1}{16}$ to $\frac{1}{8}$ of an inch is the utmost amount of wear shown by any blocks from the same position. It is therefore evident, that if it were possible to assume an absolutely uniform quality of wood-fibre, a wear of at least twenty-five years per inch depth of wood might be confidently expected from good ordinary deals under similar traffic.

Practically, of course, several incidental conditions arise which affect this estimated duration in a greater or less degree; the most important and unavoidable of which is irregularity of surface wear. A very slight fixed obstruction, whether external to, or part of the material itself, will originate a depression on each side of it in the direction of the traffic, such depression increasing in a rapid ratio with the hammering action which it at once sets up. The life of a pavement, then, becomes simply a question, first, of its resistance to the vertical impact of heavy weights; and ultimately, of the extent to which unevenness of surface can be tolerated. The only safeguard against this defect is careful attention to the homogeneous character of the material, whether stone, asphalt, or wood. In the case of compound structures—of which macadam

may be cited as a prominent one—the material is essentially the reverse of homogeneous; and hence their inferiority under heavy wear.

Another source of inefficiency in all pavements is that to which attention has already been called, viz., the failure of foundation stability, where the inevitable results of uneven surface have begun to take effect. To this failure was mainly due the abandonment of wood after all its earlier trials; latterly, however, its importance has been fully recognised, and a substantial bed of concrete, or an equally rigid foundation, is universally provided for large traffics, whatever may be the superstructure.

A third question of durability, to which much discussion has also been devoted, is that of internal decay, in respect of which some difficulty always seems to occur in citing sufficient verified cases to sustain any theory. The capacity of wood to remain intact for a lengthened term in the presence of putrescent matter, and variable degrees of moisture, is much contested. Probably the key to the whole question is to be found in the fact, that almost every phase of internal decomposition in wood is traceable to organic growth of some sort—of low development, no doubt, but nevertheless organic, and therefore subject to the primary condition of all organic growth, viz., freedom from mechanical disturbance. It has been held that a purely chemical change in the first instance initiates fungoid growth; but the Author inclines strongly to the opinion, that the process is *vice versâ*, and that it is organic germination which originates and promotes chemical decomposition. The manner in which unprepared timber is found to have endured, perfectly unaltered, under the vibratory action of street traffic, is, in this view, fully accountable; and if true, it points to a decided advantage in such timber for paving purposes over that which has been creosoted or otherwise protected. In the latter case organic decay is arrested, but only at the expense of favouring oxidation and subsequent chemical changes of a different order.

An even-grained well-grown deal, of medium weight and hardness, offers the best conditions, as far as experience goes; and against the contingencies above referred to, experience alone can furnish an absolute guarantee. It is scarcely necessary, however, to point out that the particular condition in which any specified portion of paving may happen to be adjudged as "worn out" is not one which is definable within a few months' or a year's time; and to this extent the comparative life of a pavement can only be regarded in the light of what is locally expected of it. The

standard of comparison therefore, to which street pavements are to be referred, must embody the two elements deducible from the preceding remarks, viz., the work performed (as represented by some such systematic scale as before suggested), and the sum total of direct expenditure upon it during a recognised unit of time. Applying such a test to streets of the class now under consideration, viz., those with traffics of from 200 to 400 tons per foot wide per day, it will not be unreasonable to exclude the foundation as absolutely permanent, which may be assumed to be the case if it be constructed of a sound and well-mixed Portland cement concrete of sufficient thickness to carry extreme weights. Granted, for instance, that 6 inches of a cement concrete of 5 to 1 will show no failure under a load of 3 tons per wheel, it may be reckoned as good for 100 years as for 10 years if undisturbed. An independent statistical expense of pavement over shorter periods may then be ascertained. Taking, for example, a figure somewhere about that of the present cost of wood pavements; an outlay of say 10*s.* per square yard first cost, and the same for entire renewal every seventh year, with 1*s.* per square yard per annum to cover all maintenance from the first, would show a fixed cost of 2*s.* 5*d.* per square yard per annum *in perpetuo*.

Of the three alternative materials—macadam, granite or porphyry sets, and asphalt—the first is beside the question, if only on the ground of its representing under similar circumstances a fixed charge of from 3*s.* to 6*s.* per superficial yard per annum. Granite is at the present time more nearly balanced with wood—excelling it somewhat in the matter of cheapness, but outweighed by it on the score of noise and injury to vehicles owing to its rigidity—the latter two defects insuperable, excepting at a cost which is but rarely bestowed upon it.

Asphalt, labouring under an occasional deficiency insuperable at any cost—viz., absence of foothold—is nevertheless to be regarded favourably in point of cost, and will rank high so long as the definite solution of the problem of durability stands in abeyance. Meanwhile the above notable failing, together with the difficulty attending partial repairs, must detract from the value of the money-figure to be assigned to it. In view, therefore, of the few materials which can be used, and of their several qualities and defects, the following questions comprise the chief issues to be decided.

First.—Is the policy of paving for heavy traffics to aim at reduction of first cost and the retaining of certain alleged advantages attached to systems of continuous maintenance? or at the extinc-

tion of maintenance, and the acquisition of durability combined with certain alleged disadvantages accompanying great resistance to wear?

Secondly.—Can a paved surface be made to fulfil the needs of tractive power by means of the intrinsic nature of any material, independently of designed mechanical form tending to obstruct free draught of load?

And lastly.—Can the durability of any description of wood, compatible with reasonable cost, be enhanced either in construction or maintenance, so as to place it on a commercial rank with substances of greater resistance, but of less advantage in other respects?

This Paper is accompanied by several diagrams, from which the woodcuts, Figs. 1 to 8, have been prepared.

APPENDIX.

TRAFFIC TABLE A.—AVERAGE VEHICLES per 16 HOURS. *November* 1878.

Street.	Number.	Gross Weight.	Average per Vehicle.	Average Width.	Weight per Foot of Width.	Pavement.
		Tons.	Tons.	Feet.	Tons.	
Euston Road .	12,132	10,658	0·878	44	242·2	Granite, 1863.
Edgware Road .	8,212	8,376	1·020	43	194·8	„ 1876.
Oxford Street .	16,886	17,076	1·011	57	299·5	Wood, 1875.
Regent Street .	10,796	9,668	0·900	52	186·0	Macadam.
Piccadilly . .	10,776	9,358	0·868	37	252·9	„
Parliament Street	14,306	14,380	1·005	45	321·7	„
Victoria Street .	6,040	5,780	0·957	40	144·5	„
Strand and Fleet Street . . .	16,208	13,596	0·839	37	367·5	Wood, 1877.
Gracechurch St.	12,148	13,507	1·112	32	422·1	Asphalt.
Leadenhall St. .	6,128	7,588	1·075	30	253·0	Wood, 1877.
Minories . . .	5,246	7,542	1·438	33	228·5	„ 1877.
Whitechapel Rd.	6,348	7,768	1·224	55	133·9	„ 1877.

TABLE A1.—PER 12 MONTHS.

Street.	Width.	Weight per Yard.	Number of Wheels.	Weight per Wheel.
	Yards.	Tons.	Millions.	Ton.
Oxford Street	19	288,000	18	0·30
Piccadilly	12¼	243,200	11½	0·26
Strand	12½	352,640	17	0·25
Parliament Street	15	316,880	15	0·30
Gracechurch Street	10⅔	405,120	11¼	0·37
Minories	11	219,520	5¾	0·41

TRAFFIC TABLE B.—Per 16 HOURS. *November* 1878.

Street.	Omnibus. Average Weights (Empty.. 25 Cwt. / Full .... 55)	Cabs. Average Weights (Empty.. 8 Cwt. / Full .... 12)	Loads above 3 Tons.
Euston Road	910	6,572	1,040
Edgware Road	840	3,196	928
Oxford Street	2,080	8,044	792
Regent Street	952	5,968	280
Piccadilly	3,448	6,084	728
Parliament Street . . .	3,160	6,385	434
Victoria Street	1,240	2,876	504
Strand and Fleet Street .	2,170	9,636	728
Gracechurch Street . .	910	2,428	2,180
Leadenhall Street . . .	952	1,336	1,260
Minories	..	554	1,912
Whitechapel Road . . .	600	588	1,180

[Mr. DEACON

Mr. DEACON said, before the discussion on the Papers was completed, he believed the members would come to the conclusion, at which he himself had some time ago arrived, that the subject of street pavements had been very little formulated, or placed in such a position that trustworthy information could be readily obtained upon it by those who were not directly engaged in the work. He had placed before them certain figures with reference to the cost of various kinds of pavement, and he thought the figures showed how utterly fallacious any estimate based upon first cost alone must be. They were all able to appreciate the usefulness of pavements independently of their cost; but without the knowledge, not only of their first cost, but also of the interest, sinking fund for renewal, cost of maintenance, scavenging, &c., it was impossible to appreciate their real value. So far as he knew, no tables showing the comparative costs of various pavements, taking all these elements into consideration, had before been published, and he hoped that the tables on pages 23 and 24 would in future be supplemented by similar information from other towns than Liverpool. In order to form such tables, it was of course necessary to assume some standard traffic. In the table on page 24 he had taken 100,000 tons per yard width of pavement per annum, and in the table on page 23 for lighter classes of pavement, he had taken 40,000 tons per yard width per annum. The effect of the difference of the intensity of the traffic on the same pavements would be seen by the tables. With reference to the item of scavenging, the actual cost varied very much according to the class of street, independently of the kind of pavement employed. The actual cost was not the proper test; he had therefore taken the cost which would accrue if each class of pavement were maintained to the same standard of cleanliness. He was glad that Mr. Howarth had adopted a system of reduction to a standard traffic, although he had not employed the same standard as himself, but had adopted the traffic per day per foot of width instead of per annum per yard of width. A reduction from one to the other would have to be made in order to compare the two sets of results.

Mr. HOWARTH said he had reduced the traffic of some of the largest streets in London to Mr. Deacon's standard. He desired to insist very strongly upon the importance of a system of traffic observations, so that some standard might be arrived at, by which the enduring power of the pavements in different streets could be compared. At present a large amount was being expended upon pavements, but it was a question which was the best class of

pavement for heavy traffic. This could only be decided by a comparison of the figures as to the wear and tear in different streets. He would suggest that the matter should be taken up by a recognised body like the Metropolitan Board of Works, and then be submitted to surveyors all over the kingdom. Observations might be taken simply and cheaply upon the half-hour system, and the records would increase in value as the system was continued. No matter how many days or hours or weeks were taken together; so long as each half hour in the day was specified, and identified as a separate half hour, the register would increase in value as it was continued, and at the end of a series of years there would be a check upon the traffic of any particular street. Such a system should be adopted at once if it was to be of any use. Another subject well worthy of attention was that of horse shoeing. There had been a great deal of newspaper controversy upon the question, having reference chiefly to cruelty to horses; but he was disposed to base his view on the question of cruelty to pavements. The item was a large one in the wear and tear. The only reason why he had not taken it into consideration was, that it varied *pro ratâ* with the amount of wheel-traffic; he had therefore taken the wheel-traffic as a standard on which the economic endurance of any pavement could be tested.

Mr. BATEMAN, President, quite agreed in the importance of determining the amount of traffic upon a road. He had been informed by Mr. Haywood that the amount of traffic over London Bridge, which had a tolerable width, was 18,000 tons a day. Mr. Deacon had spoken of 3,000,000 tons in a year (which would be about 10,000 tons a day), and of loads of 60 tons weight. Now, the width of the road ought to be taken into account, because 18,000 tons spread over a wide road were not so much as 10,000 upon a narrow road. There was also the question of the pressure per wheel. A load of 7 or 8 tons—1½ ton or 2 tons each wheel—would do much more mischief to a pavement than a load of 1 ton upon four wheels, or upon three wheels, which he supposed would be the average of the London Bridge traffic. Unless there were some means of comparison by which to ascertain the weight upon a square yard of surface or upon a wheel, no proper estimate could be made. According to his experience and observation, which had extended over many cities of the world, there was no city or town so well paved as Manchester, not even excepting Liverpool. Some years ago he had occasion to inquire closely into the particulars of the subject. His informant was a gentleman, since dead, Mr.

Francis, of Manchester, who was in favour of 4-inch cubes. In London, paving stones 9 inches deep were used, set upon a good foundation. Mr. Deacon had come to the conclusion that concrete foundations were the best, with stones about 7¼ inches in depth; but in Manchester no stones were ordinarily used more than 6 inches deep. That was not a matter of great importance where the stone was brought from near the place in which it was employed, but it was of great importance when it had to be conveyed a long distance. For with sets 4½ inches deep instead of 9 inches, there would only be half the weight to carry, and with the same weight of material twice the area could be paved. He could understand that stones held together by the friction supposed to be maintained between one stone and another would by their leverage operate against the action of tilting which horses, as they were shod in Liverpool and Manchester, might have to endure; but that would only arise upon such pavements as were upon steep gradients or where the traffic was very great. Mr. Deacon had stated, in reference to Manchester, that the foundation was generally cindered; but he must have been mis-informed, for cinders were never used in Manchester except in side streets or by private owners. Piccadilly was not renewed for more than twenty years. The pavements, when laid down, unless they were disturbed by gas or water pipes, or by sewers, lasted in Manchester from fifteen to thirty years, according to the traffic. They were laid upon the old foundation, with an addition of gravel, which in many cases used to be grouted with asphalt. The interstices between the stones, where they did not fix closely together, were filled with scaplings and boiled pitch.

Mr. DEACON said the traffic was reduced to a unit of yard per weight. He had suggested to Mr. Howarth that it should be done in that way, only Mr. Howarth had adopted a different unit. His authority with regard to Manchester was Mr. Laing, the surveyor; and he had himself personally examined the pavement.

Mr. HOWARTH had selected the foot instead of the yard as the standard, because there were in London so many narrow streets with very heavy traffic where the width ran into fractions of a yard, and the foot was therefore more convenient. The day also was a better item to go by than a collective statement of the whole year.

Mr. REDMAN thought that the weight of a pavement must depend in a great measure upon the foundation. No doubt for the streets of the metropolis Aberdeen sets 9 inches deep, laid upon a similar

depth of concrete would be the best possible road for heavy traffic; and 4 or 6 inches of Leicestershire granite cubes on a similar thickness of concrete would be the best for light carriage traffic. Many supposititious cases were in practice inadmissible in the streets of London, where the constant disruption of the pavement for pipe and telegraph laying necessitated constant repairs, and precluded the possibility of arriving at a perfect pavement. That might have been seen a short time back in Pall Mall, when the wood pavement was being laid: the chaotic reticulation of pipes was wonderful; and when a portion of the pavement was taken up, the difficulty of renewal was very great. The old paviors of London were to a certain extent independent of the bed. They adopted large materials, generally laid upon gravel or upon the soil found *in sitû*. Latterly the effort had been to obtain heavier beds, with a lighter material for the surface. In 1850 he had under his superintendence a tramway for heavy goods leading to the West India Docks. It was made of granite in 1824 or 1825 by the late Mr. James Walker, a former President of the Inst. C.E. When it came under his supervision a report by his predecessors, Messrs. Walker and Burges, was placed in his hands, upon the state of the tramway when the new Act was obtained, and it virtually condemned one-half of it as worn out. It was formed of Aberdeen, Guernsey, and Herm granite. The stones were much mixed. In relaying the tramway, which he did three times in twenty-one years, he carefully sorted the different granites, and the results were remarkable. One-half of the tramway was formed of Aberdeen granite; one-fourth was Guernsey, and one-fourth Herm. The entire length was 2 miles. The practice had been to use very heavy stones, that would resist any weight bedded only on gravel. The original depth was 12 inches. He found that the Aberdeen granite was worn down to half its thickness, and by introducing a bed of concrete he used the stones by re-dressing them until they became a mere veneer of granite upon concrete. Ultimately he used stones only 3 or 4 inches in thickness, until they were no longer able to bear the traffic; and the road, when laid and in good condition, was as good as when the stones were 12 inches thick. The Guernsey stone, after half a century, with a traffic amounting in the last year to 300,000 tons, had been reduced to 10 inches, the Herm to 9 inches, and the Aberdeen to 6 inches. The outside gauge of the tramway was 7 feet, and the inside gauge 4 feet, the tram-stones being 18 inches wide. Originally there were guard stones projecting considerably on either side of the trams to form the wheel-ways. He found them to be objectionable, because the light traffic

sought the projecting edge of the guard stone, and wore a groove. Ultimately, in relaying the tramway he made the entire road flush. The tramway was at first laid upon the slope of the profile of the road; that also he had found objectionable, and he had relaid it level. The vehicles varied very much in gauge. The gauge of the heavy wagons was 7 feet, and of the lighter and smaller vehicles $4\frac{8}{4}$ feet, and there were a large number of intermediate gauges. The great difficulty always was to prevent the narrow wheels of the light vehicles seeking the longitudinal joints between the trams and the guard-stones. The tramway ceased to exist after 1871, when the Act expired. The promoters of iron tramways then got an Act of Parliament, with the taking suggestion to the local authorities to lay down two lines of tramway, and to maintain a belt of paving on one-half the road. The old stone tramway was sacrificed to the modern requirements of lighter traffic. No doubt that mode of connection between the metropolis and the docks must be much missed at the present time. With regard to wood paving, all the associations that had been lately working patents had arrived at the conclusion adopted by one of the Authors, that a concrete foundation for wood paving was the best. That method had been adopted in laying the pavement in Pall Mall.

Mr. Woulfe Brenan, having been engaged for some years as manager of the Ligno-Mineral Paving Company, desired to direct attention to the life of wood pavements. In the Papers nothing had been said on that important subject. Wood paving had now been in use for seven years, and there was ample time to collect facts upon this point. Almost every kind of wood had been tried by the company he represented, including beech, elm, oak, pitch pine, and Baltic fir, and the result of his experience was, that the wood must be treated merely as a surface. The concrete foundation was the great basis of the pavement, and the shallower the block, consistently with its bearing the pressure laid upon it, the better. The pavements of late years had become improved in their form, and people did not care much about seeing an uneven pavement. Wood pavements would not wear evenly for more than four or five years at the outside; therefore, he believed that the shallower the blocks, and the smaller the cost at which they could be produced (so that there might be a new surface after four or five years), the better. The form of contract generally carried out by the Corporation of the City of London and the various vestries, provided for the prime cost of the work done, and maintenance, which in the City of London was for seventeen years. It must be well

known that no wood pavement could last for that period. A fixed amount was paid annually for maintenance, and it was supposed that after a certain number of years the pavement would be relaid. It was doubtful whether that would prove a satisfactory form of contract for the paviors, because the maintenance money was always subject to be retained if the pavement was not satisfactory. The conclusion, therefore, to which he had arrived was, that the prime cost being a small one, after five years provision should be made for a complete new surface on the road.

Dr. Paget Higgs said it had been pointed out that the chief characteristic of the difference in the various systems of wood pavement consisted in the foundation. Only concrete foundations had been referred to, but there was a system of wood pavement in which the wood was laid upon a bed of clean sharp sand 6 inches deep. Upon the sand were laid wooden blocks or cubes, and between the blocks wedges were driven, in sufficient number to hold upon the sand firmly; they were driven below the surface of the roadway to a depth of 3 or 4 inches below the level of the bed of sand; the general effect was to compress the sand to something like the hardness of sandstone. The system was used, he believed, in Chalk Farm Road and Argyll Square. The road had been subject to two years' traffic, and was now perfect. The traffic to St. Pancras was very heavy, especially the coal traffic. With reference to the concrete foundation, it seemed difficult, in fact almost impossible, to maintain a watertight surface. The constant shrinking and swelling of the wood would always create spaces through which water would percolate into the lower part, and he could not conceive how, in the case of concrete or asphalt, it could get away. It could only be from intermittent evaporation, the effect of which upon wood was well known. With sand, the bottom of the wood might remain moist, but a free circulation was allowed to the water; it was never swamped to the extent that he had noticed with asphalt and concrete foundations. The difficulty that might seem to occur with sand would be in the shifting of the blocks; but that was overcome by the method of wedging which he had described. After the wedges were driven below the surface of the wood, and the interstices filled with bituminous concrete, the wood was covered with grit sand and heated coal tar. It was difficult, in the case of asphalt and concrete, to get below the surface for the purpose of repairs, but it was not so in the case of sand.

Mr. Aveling thought that macadam had been hardly treated by the Authors. The macadamised road had been for many years a useful servant, but it had had nothing like the good treatment accorded

to wood pavement; certainly it had not of late been treated so well as in its infancy. Many of the best streets of London had been built upon a foundation known by the name of "hard core," consisting of the siftings of ash-heaps, old shoes, bottles, and pieces of tin. What chance had the macadamised road to stand upon such a subsoil as that? Every road must largely depend for its life upon the foundation. The streets of London, especially the macadamised streets, were constantly broken up by the gas and water people, who never thought of ramming the surface well, their only object being to fill up the hole they had made, and put in the macadam in a short time. Then, how were the streets repaired? Macadam taught that the stones used for the surface of the roads should not exceed 6 ounces in weight; but what was the case in Regent Street, and some of the large thoroughfares? He had lately taken up some stones promiscuously, one of which weighed 12 ounces, and the lightest 9 ounces. To enable the stone to bind, after it was placed upon a road, some substance ought to be used that would allow it to keep undisturbed with its neighbours. It would be impossible to build a house with dry bricks without the use of mortar; and it was impossible to lay a number of granite stones upon a road with any chance of success, unless something was used to fill up the interstices. In Paris the stones were broken to a smaller size than 5 ounces, or even 4 ounces. The material used was inferior to the granite employed in London, but it was broken up very finely, and the interstices were filled, not with the abominable mixture called road scrapings, but with sharp sand, sharper than was used by London builders. What London builder would think of making mortar of the binding that was put in to fill the interstices of the granite stones in the streets? A short time since, he saw in Regent Street a large number of small lumps of garden gravel, ready to be spread over 5 or 6 inches of granite. He asked a man in attendance to pour a bucket of water into a wheelbarrow full of the material. The man did so, and not a drop of water ran out, the sand absorbing it all. What could be worse to fill up interstices than anything so absorbent as that so-called sand? After rain, such a material would retain an enormous amount of moisture, which would expand when frozen, with the result that the road would be thoroughly broken up. It was not uncommon to see, in Regent Street, an inch and a half of mud on the granite, and so adhesive was it that in some places he had observed the omnibus wheel picking up the particles of granite, carrying them round, jumping over them, and leaving them in lumps, thus ruining the road. The Rue de Rivoli in Paris

one of the best macadamised roads in the world, was watered between four and five o'clock every morning, and a number of horse sweeping machines followed the watering. It was no use to have a horse sweeping machine for stuff that was half wet and half dry. It ought to be thoroughly wet, so that the machine could sweep the road clean. A macadamised road, if it was to last, should have no more dirt upon it than a paved road. The plan adopted in Paris ought to be adopted in London—to break up the material very fine, and to use more labour and less material. The present plan was to send twenty old men with picks to work up the road, and the traffic ground it down as fast as they worked it up. The proper plan was that adopted on the embankment, where a certain portion of the road was cleared—say one-third. A small portion should first be picked up, and then the granite should be placed upon it, one stone thick. It would not do to put mud in with the cubes of granite to fill up the interstices. Only that day he had got out of the street a piece of mud 1½ inch square. It was impossible for such roads to stand heavy traffic. He repeated, that justice had not been done to macadam.

Mr. ELWES had been engaged during the last two years in paving some of the streets of London with wood. When he first looked into the subject he was much struck by the difference between the durability of wood pavements as they had been generally laid, and the durability that might be expected from what was known of the properties of wood fibre. Referring to the durability of *lignum vitæ* bearings, to the treads of the steps on the Metropolitan Railway made of hardwood with the fibres on end, and to a case mentioned a week or two ago, in which a beechwood cog had been under pressure twenty-six years, and had made thirteen million revolutions, transmitting 100 HP., it was somewhat striking that wood pavements had lasted so short a time. His experience led him to believe that it was not so much the want of durability in the material as the way in which it had been applied. It appeared that two reasons had contributed to the early failure of wood pavements. The first reason was the want of a proper substratum, the wood paving itself being treated as a road, instead of as merely a wearing surface to the road; the other was the wide joints, referred to in one of the Papers, causing the abrasion of the edges of the blocks and the giving way of the fibre, not by fair wear and tear, but for want of lateral support. Experience of Henson's system of wood paving showed that wood, properly applied, had considerable durability. He scarcely went so far as Mr. Howarth in estimating the wear as only 1 inch in twenty-five

years, but he thought under ordinary circumstances it would not exceed $\frac{1}{8}$ inch in a year. He considered that asphalt supplied what was required, a wearing surface to the road underneath, which was perfect in every respect except two, namely, the cost and the slipperiness. There could not be a better material for the real road than 6 inches of good Portland cement concrete. What was wanted was some wearing surface at the top which should not cost too much, which should last, which should be impervious to water, and which, without causing too great traction, should give a fair foothold to the horses. He agreed that if, with one section or slab of pinewood laid across the road, the effects of expansion and contraction could be got rid of, they would then have what was required. Unfortunately, they could not have that, and were therefore obliged to use wood in blocks. He also agreed in thinking that the shallower the blocks the better, provided there was sufficient stability. The objection to deep blocks was this: for a wear of eight or ten years, only 1 or $1\frac{1}{2}$ inch of wood was required, and by giving 6 inches thickness so much capital was locked up during that time. When the wood was taken up the blocks could not be used again, and there was accordingly a dead loss. What was really wanted was some mode of putting down a surface of wood fibre set on end, about 2 or $2\frac{1}{2}$ inches in thickness, in such a way as to provide for expansion, and with sufficient connection between the parts to prevent their being picked up by the wheels or disturbed, as they would be if they were laid in blocks only 2 or 3 inches in depth. Mr. Deacon had referred to a specimen of Henson's wood paving laid at Liverpool, which, he said, had maintained its form better than other wood pavements of which he had had experience; that, Mr. Deacon said, was owing to the nature of the substratum—a suggestion that he thought was a little unkind. He had no objection to Mr. Deacon taking half the credit for his excellent bituminous concrete, but he might have given the other half of the credit to Henson's system. In other places, such as Oxford Street, the Minories, Fleet Street, Leadenhall Street, and in the Uxbridge Road, where the pavement had been laid for some time, it had preserved its shape as well as in Liverpool, and the concrete underneath was not bituminous.

Mr. H. S. COPLAND said he had had considerable experience of wood pavements, having been the inventor of the asphaltic wood pavement, so largely used in London. It was specially designed to obviate the objections that had been taken to paved surfaces, particularly wood surfaces, namely, that they were subject to

unequal subsidence, unequal wear, and that they afforded an insufficient foothold to horses. Granite pavement was no doubt excellent for heavy traffic, but a great objection to it was that water percolated through the surface. If there were any irregularities in the quality of the concrete, the water quickly discovered them, caused disintegration, a subsidence took place over the immediate part, and the road was soon destroyed. That effect was often seen in London. An excellent piece of paving was laid eight or nine years ago by Messrs. Mowlem, Burt, & Co., in Oxford Street, upon a foundation of concrete. A better foundation could not be made, but there was no mode of preventing the surface water from reaching it; the result was seen in irregular subsidences, and the road had to be relaid within six years. He agreed in the advisability of using shallower blocks for wood pavement than were at present employed. If the surface water was prevented from reaching the foundation, it remained tolerably intact. With that object he had placed an impervious layer of asphalt beneath the wood blocks, through which it was impossible for the water to reach the concrete; the concrete therefore was undisturbed, and the surface remained perfect. No other substance would keep out the moisture so well as asphalt. If the blocks were laid upon that surface, and intimately connected, in order to secure the stability of the blocks and prevent their rocking on their beds (as they did in most systems of wood pavement), very shallow blocks might be used, and the original cost might in that way be reduced. The blocks which he had used were from 5 to 6 inches in depth, because there was a prejudice in favour of deep blocks, not because he approved of them himself. He thought that 3-inch blocks, properly keyed, with asphalt joints, were sufficient for all practical purposes. The real road consisted in the foundation, and not in the surface. The surface was to prevent the wear of the traffic from destroying the road beneath; and the wear and tear of the attrition of the traffic was the only wear that should really exist in a road. The life of a wood pavement had been stated at about four years. His pavement had been down in Cannon Street nearly five years, under perhaps as heavy a traffic as existed in any city in Europe. It was still, practically speaking, perfect on its surface; there had been no subsidence of the foundation; the surface attrition had merely worn the blocks about ½ inch, and they ought to remain another four years before they required to be removed. The result was, that having laid 5½-inch blocks in that position, he looked upon 2½ inches of that depth as representing so much extra capital sunk unnecessarily in the cost

of that pavement. The blocks would wear for a depth of from 1 to 1½ inch without requiring to be replaced. If the wood was properly selected in the first instance, all sappy wood being rejected, and only that of a tenacious character retained, it would wear with a comparatively uniform surface down to 2½ or even 2 inches. He agreed that the macadamised roads had been very ill used. Macadam perfected his system by the use of only small stones. Mr. Copland rarely went through any of the London streets under repair without feeling regret at seeing a good road for moderately light traffic abused by having immense stones put upon it. Instead of stones of 2½ or 3 ounces, according to Macadam's recommendation, some stones were used nearly 1 lb. in weight. The idea seemed to be to lay those stones in order to cover a given surface with as little labour as possible. Sand foundations had been tried in San Francisco and in several other American cities; and although they had done tolerably fair service for a time, it had generally been found that the blocks had not been sufficiently united at the base, and that they soon shifted. The great thing was to key the blocks down, to prevent them from shifting. If wooden blocks were keyed to one another, and firmly cemented over an impervious surface, a monolithic slab was formed over the road which could not subside; and the more firmly the blocks were connected in that way the shallower were the blocks that could be used.

Mr. Price-Williams wished to make a few observations on the table showing the total cost of the various pavements. The remarks of the President and the replies of the Authors had partly met one question, but not quite. He gathered that the standard traffic of 100,000 tons per yard was confined to a yard of width; therefore, in order to arrive at the total amount of traffic over the road, a multiple into the width would be required. He did not understand the sixth column in the table on page 24, representing the sinking fund invested at 3 per cent. compound interest. The life of a wood pavement had been stated to be about four years; but, according to the first figure in that column, 1·8*d.* per annum was to be set aside as a sinking fund to be invested at 3 per cent. per annum, and this he found would recoup the principal, viz., 12*s.* 1*d.* in about 40 years; and in the case of the pavement constructed in Liverpool for heavy traffic, it amounted to the amazing term of 80·78 years. In the case of No. 4 pavement (7½-inch sets), the ultimate life was 30 years. He wished to ask whether he was correct in his inference, or whether Mr. Deacon had some other meaning for the sinking fund which was not apparent?

Taking the total annual cost per square yard, he had arrived at some comparative results. He found, for instance, with regard to the old Liverpool pavements, that the amount of their first cost was spent upon them in 10·8 years. Measured in that way, the present pavement in Liverpool for heavy traffic appeared to show the best results. He considered that the tables he had referred to and those in Mr. Howarth's Paper ought to be on a common basis before any true comparative results could be arrived at. With regard to the No. 7 wood pavement, the original cost of which per square yard was 15*s.* 1*d.*, the annual cost of its maintenance and renewal was very large as compared with the others, the total first cost being spent in the short period of 7 years. He noticed also that the No. 7 wood pavement, in the second table (page 23), with a traffic of 40,000 tons a-year, showed about the same money life. The original cost was 15*s.* 1·5*d.*, and the annual cost 1*s.* 8·5*d.*, giving a measure of life of 8 years. He considered that valuable materials had been given for obtaining the relative cost of maintenance of the different forms of roads. Having regard to the enormous sums spent in the metropolis, he thought that a little more attention to the comparative cost of the pavement would be attended with beneficial results. The macadamised road had, no doubt, answered its purpose very well; but its time had gone by for the heavy traffic of the metropolis. It was evident that a different class of road was needed. He agreed that, with a substructure of the permanent character that had been described, the depth of the wood or stone pavement was a matter of secondary importance.

Mr. E. A. BERNAYS said his experience had not lain much in paving roads and streets, but he had had to do for many years with paving to carry heavy substances, requiring a very good road that would stand the heaviest weights. In town paving many things might determine whether macadam, wood, asphalt, or granite, should be used; but whatever material was employed, all who knew anything of the subject would agree, that the first element of success was a good foundation. His experience entirely confirmed the statements of the President, that the depth of stone pitching on sets had been steadily diminishing. His first recollection of a stone set on a heavy road was pieces of granite 9 inches deep, very rough on the bed, and not much better on the surface, with joints scarcely better than either. In those days the foundation upon which the stones were placed was a very indifferent one. The pavement was either laid carelessly in loose gravel, or (when people began to understand the importance of a

good foundation) upon a lime concrete, indifferently made, and perhaps still more indifferently put in. With Portland cement a good concrete could be made 6 inches thick, which would be sufficient to carry the heaviest traffic of the largest towns in England. With that foundation, the thickness of the sets had been reduced, and might be reduced still further. Having had to lay a great many roads to carry heavy weights, such as armour plates and boilers, &c., he had adopted 4-inch cubes instead of the 9-inch sets used in his younger days, and he had found in practice that there was no better way of laying them than on a 6-inch bed of concrete. He preferred to arrange them when the concrete was wet, so that the concreters were only a little in advance of the paviors. The stones, when laid on, were slightly tapped, not hardly rammed, and the grouting soon followed; that was done with slow-setting Portland cement instead of sand, the whole being rammed before the grouting and concrete were set. For getting a foot-hold for the horses, he preferred to keep the sets at some reasonable distance apart, and to grout with fine gravel instead of coarse sand. It was cheaper, and the small stones would set in hard between the roads, and make them so solid that they could only be split up by steel wedges. The misfortune was, that, in large towns, gas and water companies and sewer makers were so often obliged to destroy the surface, but he believed that such roads were more easily repaired than any others. He could give no opinion worth anything as to the merits of wood, asphalt, or macadam, in regard to durability and cost; but he could safely say that a road made in the way he had described would stand any traffic that might be put upon it; and it might be made at a moderate cost, because, by reducing the thickness, and consequently the cost, of the sets, a portion of that saving would be available for making the foundation better.

Mr. LOVEGROVE, as a road surveyor of twenty-five years' experience, would like to make a few remarks on the subject of the Papers. He was glad to hear the observations of the President with reference to the depth of paving sets. A considerable length of tramway in the Hackney district was laid with 4-inch sets, and they had stood remarkably well, and in some cases better than the 6-inch and 8-inch sets. Sets deeper than 4 inches were difficult to remove for repairs or openings. For a portion of the length the joints had been completely filled with bitumen, which added to the durability and cleanliness of the stone. The most trying position for stones was next to the tram rail. There was a perceptible difference in the wear in that position between Guernsey

and other stones. Nothing endured so well as Guernsey; other stones had been used side by side, and a groove had been more rapidly produced. He found, as the result of some few calculations, that the maintenance of paved surfaces was reduced to a very small sum. In round figures, it was about 1*d.* per square yard per annum. In one case, where the maintenance of macadam road had reached 2*s.* 6*d.* per square yard, the road was partly paved, and the cost had been reduced to 1*s.* 8*d.* When the average cost of maintenance of a macadamised road reached 2*s.*, he thought that, as a matter of economy, the surface ought to be paved. Much had been said against macadamised roads, but he did not know how the public could do without them. With reference to hard-core foundations, to which reference had been made, he could only say that old boots, tin kettles, and other things of that kind, formed a capital first foundation for a new road over a meadow. In laying out a new estate, he knew nothing better, except perhaps burnt ballast. He had never heard of granite being laid on hard core; granite was not laid until a road had been worn for many years. The first top material used for a road was usually gravel. After long wear the traffic produced a good solid gravel foundation, upon which a thin coat of granite might be laid. He had found that the use of a steam roller had caused a great saving in the material. The statistics of twenty-one different streets (see table page 63) showed the cost, including granite, rolling, watering, labour, and covering material, to vary from 9¾*d.* to 1*s.* 9¾*d.* per superficial yard. The thickness of granite laid on varied from a minimum of 1·04 inch to a maximum of 3·04 inches, according to the condition of the road upon which the granite was laid. The old system of laying granite stones was barbarous—that of allowing the vehicular traffic to work and wear the granite until a sufficient portion was pulverised to cause it to bind together. The steam roller had the effect of pressing the material into a thorough bed, and it presented to the vehicular traffic only one of its surfaces. When the surface was broken up after twelve months' wear, the angles would be found on the under side of the stone in a perfectly good condition. In proof of this a number of stones had been taken up from a road repaired on the old system and others from a road repaired by the steam roller. In the former case the stones were rounded, and in the latter the angles were preserved intact on the under side. A capital road might be turned out with macadam. With regard to covering material, he sometimes used gravel and sometimes road sweepings. Road sweepings formed a good material for covering

Cost of Repairs to Roads by Steam Roller.

—	Roadsmen and Watchmen.			Hire of Roller.			Water Carts and Water.			Sharpening Picks.			Granite.			Surplus Hoggin, &c.			Area.	Thickness of Granite laid on.	At per Square Yard.		Total Cost.		
	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.	Sq. Yards.	Inches.	s.	d.	£.	s.	d.
De Beauvoir Road.	7	3	6	20	5	0	3	5	2	0	17	0	236	6	6	7	16	8	3,295	3·00	1	8	275	13	10
Church Road . .	1	3	3	2	5	0	0	8	8	0	0	4	37	1	9	0	18	4	570	3·03	1	7½	41	17	4
Holly Street and Trafalgar Road .	11	16	3	31	10	0	3	3	0	0	14	0	297	11	3	10	3	4	5,060	2·45	1	4¾	354	17	10
Sandringham Road	10	1	3	30	0	0	2	12	6	0	8	4	315	13	6	9	16	8	4,997	2·64	1	5½	368	12	3
Bradbury Street .	1	4	6	6	0	0	0	10	6	0	1	4	41	8	0	1	8	4	557	3·10	1	9¾	50	12	8
Lansdowne Road .	14	17	6	21	15	0	2	17	9	2	11	6	247	10	9	8	6	10	4,901	2·11	1	2½	301	0	4
London Fields Path	11	18	0	15	0	0	1	11	6	0	2	0	79	7	0	6	6	2	2,259	1·46	1	1¾	230	10	8
De Beauvoir Crescent	5	8	6	9	15	0	1	14	1	0	9	10	95	14	9	3	5	0	1,538	2·60	1	0¼	116	7	2
Urswick Road .	3	3	0	3	0	0	0	10	6	1	8	4	9	9	9	1	14	8	380	1·04	1	0	19	6	3
Victoria Park Road	50	6	3	51	0	0	8	13	6	7	11	4	426	1	6	18	7	10	7,466	2·38	1	6	562	0	5
Berger Road . .	8	15	0	19	10	0	1	1	0	1	9	0	140	11	9	2	15	2	2,409	2·44	1	5⅓	174	1	11
Terrace Road, East	8	6	3	6	0	0	1	1	0	1	16	8	71	11	9	2	18	2	1,090	2·74	1	8	91	13	10
Terrace Road, West	4	5	9	3	0	0	0	10	6	1	3	6	30	3	9	1	11	10	611	2·06	0	10¾	40	15	4
Grove Street . .	6	7	9	7	10	0	1	6	3	0	17	0	63	16	6	3	16	6	876	3·04	1	10¾	83	13	8
Well Street (south end)	6	16	6	6	0	0	1	1	0	1	4	2	43	2	6	2	3	0	823	2·18	0	10¾	60	7	2
Well Street (north end)	31	6	6	21	0	0	1	1	0	6	4	6	206	2	9	5	11	6	3,080	2·79	1	9	271	6	3
Victoria Road . .	11	4	0	18	0	0	..			..			104	7	3	2	6	0	2,270	1·92	1	2¼	135	17	3
Water Lane . .	22	11	6	21	0	0	3	13	6	4	17	8	119	17	9	7	1	8	2,360	2·12	1	6	179	2	1
Paragon Road . .	18	11	0	18	0	0	3	3	0	5	17	8	117	6	0	5	9	4	2,576	1·90	1	3½	168	7	0
Stanley Road, &c. .	5	8	6	9	0	0	1	11	6	0	13	8	25	17	6	3	4	8	517	2·09	1	6¾	45	15	10
High Street, Homerton . . .	44	17	10	54	15	0	9	5	11	9	2	2	222	10	6	14	3	8	8,510	1·10	0	9¾	354	1	1

the granite, especially if heaped for a time; all the organic matter was in that way destroyed. The material should be distributed fairly over the new granite before watering and rolling. Londoners were very impatient, and the roads did not get sufficient rest. Newly repaired roads should be allowed to rest a fortnight before being used.

Mr. GEORGE FARREN stated that, as the engineer in charge of one of the large granite companies to which Mr. Deacon had referred, and which had supplied Manchester for thirty-five years, he had had considerable opportunities of seeing different methods of paving in various cities of the kingdom. The subject was well worthy of attention, considering what a large portion of the national wealth consisted in roads and highways, and the large sums annually levied throughout the kingdom for their maintenance and repair. He would say nothing as to the various qualities of stone, the data respecting which were at the command of every engineer; but, in his opinion, the subject of foundations had been greatly neglected. The progress of the art of road making had advanced by very slow degrees. Without a good foundation no road could be properly made. Many corporations paid no attention to road foundations, and he knew of one case where the paving sets had been simply placed on the sand on which the town stood. Mr. Deacon had started a new system in making a thoroughly good foundation.

Mr. SHELFORD stated that it was not Macadam, but Telford, who insisted upon a good foundation for metal roads. Macadam at Bristol worked, not upon new roads as Telford did, but upon the repair of old roads. His principle was to make a good surface upon a bad foundation. It was because he took the roads as he found them, and converted bad roads into good ones, that his name had been preserved in connection with public roads, instead of the name of Telford. Reference had been made to Manchester as the best paved city in the world. He had lately been there to ascertain the mode of paving, and to compare it with that adopted in London. He was informed that the heaviest paved street in Manchester consisted of 6-inch sets of Welsh granite, which were set upon the soil, or upon the foundation of the old road, bedded in ashes or gravel. The interstices were filled with hard gravel, and grouted with asphalt. In Bermondsey, where the traffic going to the docks was perhaps the heaviest in London, the best pavement was considered to be a concrete foundation of Portland cement 6 inches in thickness, with Guernsey granite cubes 7 inches in depth, grouted with cement. Considering that the traffics were the same, and that the Manchester pavement was undoubtedly good, at least

equal to that in London, if not better, it was important to consider whether it would not be possible to improve the London pavements, or at all events to ascertain the essential difference between the two principles. In Manchester the Corporation appeared to follow Macadam's principle, which was to maintain a good surface, and make it impervious to water. In London the authorities seemed to rely upon the concrete foundation entirely, and to care little about keeping the water on the surface away from the concrete.

Mr. HADDAN said he had travelled over Turkish highways, where round boulders imbedded in mud formed first-class carriage roads; and Russian tramways, where pine logs were used to fill in the ruts; and faults quite as striking were committed in the formation of English pavements. The improved wooden pavement abandoned a water-tight surface, and ensured destruction to its materials by the employment of a hermetical substratum which had no possible drainage outlet, while its surface was not cambered enough to afford drainage. Why should not the fact be accepted at once, that with the increased width of streets, the corresponding camber for obtaining proper surface drainage was impossible, and should therefore be eschewed. A system of perfectly level paving might be adopted, with free down drainage between all the joints to an impervious substratum cambered to any extent necessary to insure perfect drainage. Tramways were not suitable on properly cambered roads, and for this reason alone camber should be dispensed with in towns. Wood pavement had always been attractive. It afforded a solution to the tramway difficulty, for horse traction thereon, with the average London street inclines, was no greater than on the grooved rail; while, by incorporating the wooden tram-rail in a wood pavement, the perfect homogeneity of the surface, a *sine quâ non* in road making, was attained. He had found from experiments that for every road material, from a rail to gravel, there was a most suitable gradient, and that the frictional resistance offered by wood pavement suited the average gradients of most cities. Hitherto efforts had been directed towards overcoming the roughness of roads, but asphalt, under certain conditions, proved that road surfaces might be made too smooth to enable the wheel to overcome the axle friction; he had himself seen the hind wheels of omnibuses slide laterally on the camber of such roads owing to the lack of sufficient bite to proceed forwards. He quite endorsed the opinions as to the use of sand as an intermediary between the surface and the foundations, if confined as explained. It was used almost universally in Paris.

Mr. LYNDE said the Papers were valuable and exhaustive; and,

as far as Liverpool was concerned, every information had been given of the cost and value of the paving in that town. Some mistake, however, had arisen with regard to the foundation of the paving in Manchester. In the Manchester streets there was generally a good foundation of old macadam, and on that foundation was laid the paving bed, and the pavement effected in the ordinary way. In the out-townships, in fields and open land, the ground was excavated 18 inches below the formation of the level surface of the pavement, and a layer of 12 inches of cinders was put in. The traffic was turned on to that. The kerbs were put in, and the level fixed and surface made good from time to time with gravel or old macadam, or any stuff good for the work, until it was ground down to a solid surface with the ordinary traffic. Then the road was treated in the same way as streets in the town, and paved upon that foundation. No concrete was used, except when, in paving, a soft place was found; it was then dug out, and made good with concrete, so that it should be equal to the other portion of the roadway. The stone used was Welsh granite, the best being the Carnarvon. The joints were filled in the way described, with chippings and asphalt. It might be useful to those who had to estimate for paving, to know the number of square yards a ton of granite would cover, of different depths. With 6-inch by 3-inch sets, one ton covered $3\frac{2}{3}$ square yards; 5-inch by 3-inch sets covered $4\frac{1}{3}$, and 4-inch by 4-inch sets covered $5\frac{1}{3}$ square yards of paving. The average cost of re-paving in Manchester with 4-inch sets was 10*s.*; 5-inch, 11*s.*; 6-inch, 12*s.*; and 7-inch sets from 13*s.* to 13*s.* 6*d.* per square yard.

The details of the 6-inch paving per square yard were as follows:

	s.	*d.*
Welsh granite sets at £1 7*s.* 3*d.* per ton delivered . .	7	$5\frac{1}{4}$
Grouting with asphalt	1	2
Forming bed and laying sets	1	0
Carting	0	5
	10	$0\frac{1}{4}$
Superintendence and plant, 10 per cent.	1	0
Total	11	$0\frac{1}{4}$

They never used 7-inch sets, excepting where the traffic was very heavy and on an incline. One ton of 7-inch sets would suffice for 3 square yards of paving.

The greatest weight on four wheels that he ever heard of as coming upon the streets of Manchester had exceeded 50 tons.

That was a locomotive engine and tender complete, carried on a truck with four wheels. This only occurred on one occasion, and then the pavement was not disturbed. He had just previously put down a weighing machine to carry 50 tons, and of course the load could not be taken over it; the power of the machine was accordingly increased to 60 tons. He calculated that for all the bridges he had constructed in Manchester—and they were a good many—a moving load of 60 tons on four wheels could go over any bridge with perfect safety.

Mr. RAWLINSON, C.B., said it was not a very profound remark that good roads were at the root of civilisation. Yet no nation which ever made much progress in civilisation had neglected its roads; and the nations of antiquity which had remained stationary had not been road makers. There was little record that the Jews were road makers; the Turks certainly never were road makers. The Romans, who were the greatest civilisers and conquerors, were also the greatest road makers. The English, within the last two centuries, had become great road makers. They were in a compact island; and were the wealthiest people the world had ever seen, and as a matter of course had grown into that state of civilisation in which roads had become necessary. They need not, however, flatter themselves too much, as it was only recently they had more fully commenced to learn that roads were really necessary to the enjoyment of wealth. When he went into Lancashire, in 1863, to assist in administering the relief fund, he found large towns, Bolton, Blackburn, and others, in which there were miles of streets —that was to say, tracks—laid out having houses on both sides, along which wheels could not travel in wet weather. From 1863 to 1866 there were formed in Lancashire about 400 miles of new streets and roads, some macadam and some pavement. There were now in England many forms of roads. Macadam introduced the system of breaking hard stones down to a uniform size; preparing good foundations; effectually draining by side ditches; and laying roads to a certain rounded contour, the traffic wearing them down to a proper consistency. Those roads served admirably well for highways and turnpikes; but they had been introduced into streets for towns, and were to be found in nearly all the towns in England. For small traffic they served comparatively well; but though they were cheap to make, they were costly to maintain. In fact, as traffic increased, a macadamised street became literally a stone mill, the stone being ground up in wet weather into mud, and in dry weather into dust. In order to find an example of what a street ought not to be, there was no need to go farther than

Parliament Street. Anything more stupid or cruel than the construction of the road opposite Whitehall and in Parliament Street, it was impossible to imagine. How many tons of macadam had been laid down upon that road, or how much money expended in steam and horse rolling, he could not undertake to say, but now, after two hours' rain, it was a mass of sticky mud; or if there were two hours of dry weather, it became a cloud of filthy dust. If that was roadmaking in this scientific age, for the main thoroughfare to the Houses of Parliament, in the richest city in the world, he for his part did not know what roadmaking was. He maintained that a cheap road—that was cheap in its first construction and in the cost of its material—might be the greatest waste of money that any local authority could incur. There was one feature about London and its macadam roads which to many persons was a great nuisance, though he personally considered it a great advantage, namely the occasional mud. Considering the amount of urine and dung dropped about the streets by horses, if it were not for occasional rainy weather and muddy macadam-made streets, he did not know what would be the consequence. Every time he saw a few inches of mud scraped off the London streets, he was thankful that the mud was there. But that was the fault of macadam, as it absorbed all that fell upon it, and unless the mud was taken away a pestilence might ensue. London street mud was a noxious and destructive compound, injurious to clothing, to carriages, and to harness. Mr. H. Graves, the print publisher, stated that he could clean an engraving from oil or from ink, or from ordinary dirt, but not from London street mud. With regard to paving, the test of good or bad paving was the amount of mud seen upon the surface; because the mud found upon a paved street was not the result of the wear of the pavement, but the working up of the bad foundation upon which the pavement was laid. Engineers were now suggesting a form of pavement which apparently would make what a good street ought to be—that was wood pavement. Three or four kinds of wood pavement had been tried; some, as in Pall Mall, with wide joints an inch apart, filled in with gravel; some laid upon two layers of boards, the boards resting upon sand; but recently it had been found better to form a permanent bed of concrete, and to lay the wood pavement upon that. In some instances the wood pavement was laid at right angles to the axis of the street; in others, as in Pall Mall, it was diagonal. Riding over these different forms of wood pavement, he could tell immediately when changing from one form to the other; and

unquestionably the wood pavement laid block to block upon a bed of concrete, made solid, was preferable, as it was smooth, and was not muddy in wet weather, nor was it dusty in dry weather. It might be too early to predict the future of wood pavement, but so far the best wood pavement apparently yielded good results. It was not the cheapest pavement in first cost that was the best, but that which was the easiest to travel over, and was least destructive to vehicles. Assuming that a private carriage travelled 2,000 miles in twelve months, he found it cost for the shoes of horses, harness, and everything, about £50 a year, or about 6*d.* a mile; or on an annual house rental of £300, at a rate of 3*s.* 4*d.* in the pound. Anything that would reduce that cost, by giving smoothness and facility, would be an enormous advantage to the users of the road; while anything more cruel than laying macadam and allowing carriage-wheels to crush it into form, could not possibly be conceived. He submitted the query whether the term "paving," so long used to denote stone, could be properly applied to wood.

Mr. Edwin Chadwick, C.B., said upon this question there were some economical points which appeared to him to be, at this time especially, of great importance. In the present condition of the country it was of vast importance to reduce the cost of internal transit to the uttermost, that was, the cost of transit on roads in competition with the cost of water transit. If by the improvement of the rural roads four horses could be enabled to do the work of five the saving to the country in agricultural horses would not be less than seven millions per annum. There was also the cost of the urban transit, and he believed, on the whole, the cost of transit to be saved by improvement in roads would not amount to less than from seventeen to thirty millions a year. Viewing the relation of this country with other countries, the great distances from which some produce had to come, and to which manufacturing produce had to be returned, and how heavily weighted this community was with the cost of transit, its reduction was one of the greatest problems with which engineering science could occupy itself. From that point of view he regarded the discussions that had taken place with great interest; but as far as he had heard, this was a point which had yet to be considered. One speaker was very pathetic in his statement of the sufferings of the granite—how it had been ill-treated; but he forgot how wheels had been ill-treated, how carriages had been ill-treated, and how the riders had been ill-treated in having to plough through macadam with three or four times the force that an improved road

would have required. The President had said that Manchester was one of the foremost towns in respect to its pavement. But, for the attainment of definite comparison, the tractive force should be tested by the dynamometer. He had not heard one word in the course of the discussion as to the economy tested by the dynamometer. In connection with the Society of Arts, that point had been examined in respect to the metropolitan roads, and the resistance of one road had been found four times as great as that of another. The differences were as 1 and 2, until with macadam, and especially new macadam, it rose to 1 to 4. One horse on a good granite tram would do as much effective work as four horses ploughing through fresh macadam. There was another great problem which had not yet been properly attended to in administration, namely, that the strength of the road was as its weakest part. A main road might do very well for one horse, but the bye-road and the side road might require two or three horses; and that was the case throughout the whole country. Macneill and others had shown that one horse could, on a granite tram, do the work of at least three; and although Manchester was stated to be the finest paved city in England, he ventured to say if granite or asphalt tramways were introduced there, there would be a saving of 2 out of 3 of the force required. This tram system had been carried out in some of the northern Italian cities, and there the tram provision for the wheel track was uniform. Lord Palmerston, who rode over them and experienced their great comfort, said that he despaired of anything so good being introduced in England as was to be found in the northern cities of Italy. One of the best materials of the time, and one that would be available instead of the granite tram, was asphalt; but that seemed to have been neglected. Most remarkable results had been shown as to the capabilities of that material. It had been down in some parts of London for seven years, and he was assured that the wear and tear by abrasion were as nil compared with any other material; on taking up the roads they had been found to have suffered no reduction of weight, but simply some wear and tear by abrasion. No other material had given results equal to that. On the whole, he was convinced that by providing a wheel track there would certainly be a reduction of from one-half to two-thirds of the tractive force required in London.

Mr. GILES, M.P., said everyone must agree with Mr. Rawlinson as to the advantage afforded by good roads over ordinary macadam. There was the saving of money, which was the most popular way of putting it; and all must feel that there was not only a saving of

money, but a great increase of comfort by the adoption of wood pavements. Although a great deal had been said in favour of macadam roads, he quite endorsed all the observations made by Mr. Rawlinson as to the nuisance in dry or muddy weather. Another point which had been passed over was the inconvenience, not only to shopkeepers along the road, but to travellers generally, in consequence of the frequent need of repair. When the street was up the dwellers in that street suffered in consequence of the stoppage of traffic. He did not know to whom the public were indebted for the re-introduction of wood pavement in the last few years, but he could remember that as long as forty years ago wood pavement was introduced in London, but it did not last long. Perhaps the principle was not so well understood as now. He agreed with what had been said as to the great depth of the sets being unnecessary; but he thought it would be desirable to thicken the depth of concrete. A layer of 6 inches was scarcely sufficient for a heavy traffic; and he imagined one reason that the Cleopatra Needle was placed in its present position was in consequence of the difficulty in finding a road that would carry the weight over it. He thought the statistics of road traffic were utterly unreliable, because with ordinary cab or carriage traffic, roads would last for many years; while with any heavy traffic, or with a traction engine passing over it, any ordinary road was ruined, and had to be almost remade. One remark had surprised him, namely, that some wood-paving companies had made contracts for keeping their pavements in repair for seventeen years. There was no evidence of any wood pavement lasting beyond five or six years. Up to that period there was, perhaps, no particular unsoundness in the wood, but there was certainly wear on the surface. The perishable nature of wood, notwithstanding its being creosoted, was patent; and when decay once began it went on in an increasing ratio, so that though the pavement might be good for five or six years, after seven or eight years it must be altogether useless.

Mr. Reader Harris understood that Mr. Deacon proposed to make the surface of wood pavements impervious to moisture, but he did not quite understand that from Mr. Howarth, and he wished to know, whether the wood pavements were intended to be water-tight, and if not, what means were proposed for dealing with the sub-drainage. The question of water-tightness was brought before him rather forcibly some years ago in a tropical country, where wood pavement was put down for the first time. It was not well constructed; the foundation was indifferent, although not so bad as some that had

been described. However, the wood was laid, and shortly afterwards heavy rain fell and a hot sun came upon it. The wood began to expand; it removed the kerbing stone, and before very long it had succeeded in demolishing the lamp posts. The success of wood pavement greatly depended upon the superstructure being impervious to moisture; and the division between the blocks should be filled with some material which, while it gave scope for the expansion of the wood, would be as hard, or nearly as hard, as the wood itself. When that was once done, what would be required would be to keep the roadway clean, for cleanliness was quite as important to pavements, and as essential to the maintenance of the roadway itself, as it was to the health and safety of those who travelled over it.

Mr. J. DICKINSON BRUNTON said an observation had been made by Mr. Deacon to the effect that "the difficulty of sufficiently dressing one surface of such sets by hand is no doubt very great; but the design of a machine for the purpose is well worthy of attention" (*ante*, p. 26). He added, "The problem must not be confounded with that involved in the dressing of any ordinary rock, even the hardest used in building, or even with that of dressing granite for paving purposes." The subject had been brought urgently before Mr. Brunton in the way of an application for a machine to dress these sets, and that by several proprietors of granite quarries producing large quantities. He had felt that there was no possibility of dealing with these sets by a machine as cheaply as they could be dealt with by hand; but, from the remarks made by Mr. Deacon, it appeared that he was, perhaps, in error in regarding that as an insuperable obstacle, and that although the use of the machine for dressing these sets might involve some small extra expense, that expense might well be laid out. The machines of his invention were able to dress stones of any hardness; and naturally those who were interested in the production of these sets, had concluded that by these machines such sets might be dressed. When machinery was substituted for hand labour it generally followed, that there was not only an improvement in the quality of the work, but economy in point of expense. In this case, however, the application of machinery was not so much in place of hand labour as in addition to it, and must therefore be attended with some additional expense. The question was what would that additional expense be, and would the advantages gained justify it? It would be necessary, before bringing the sets to a machine, to hammer-shape them as was done at present, and the work of the machine would be to give a true and even surface to

one of the faces. He estimated that the face of a set 7 inches long and about 3 inches wide might be produced for about ¼*d.*, reckoning four machines at work, each dressing about sixty sets an hour for say seven hours in the day. The sets would be held by a species of parallel vice fixed on a table; there would be several tables to each machine; the rate of movement against the cutters would be 36 inches per minute; and half the surface would be dressed from one end, and the other half from the other, so as to avoid any breaking of the edges. He had perhaps said all that was necessary to direct attention to the fact that there was a machine by which the surface of the sets might be dressed, and a true, plain surface produced, which, according to Mr. Deacon's account, was important, for diminishing the traction and the wear of vehicles, and for the production of good roads.

Mr. STAYTON having had daily experience in the question of maintaining a portion of the roadways of the metropolis, as the surveyor of Chelsea parish, desired to thank Mr. Deacon for the valuable information contained in his Paper. In one part he stated that it was absolutely necessary that concrete should be in position something like eight days before it was paved over. He most cordially agreed in that opinion. No doubt many members of the Institution had seen what was going on elsewhere, but in Princes Street, Edinburgh, which was being repaved from beginning to end last year, the work was carried out in a systematic and satisfactory manner. The concrete was 9 inches thick, and was left in position a fortnight or three weeks before any paving stones were laid upon it. By that time it had become hard. His particular object in mentioning that was because it was rather a departure from the ordinary way of laying paving stones, which was generally done in too great a hurry. Instead of being embedded upon sand, they were embedded upon a thin bed of concrete, composed of Portland cement and granite chippings. Just sufficient was mixed up to enable it to be covered while fresh; the stones were put in place and smartly tapped, and immediately grouted with cement grout; but there was no ramming, or no pavior's hammer swung between the workmen's legs, as had been described. After that was done nothing was allowed to pass over it for a fortnight. The consequence was that all the joints became thoroughly set, the surface was maintained intact, and one of the best pieces of pavement he had ever seen was made. Of course there was great difficulty in London in closing streets for such a length of time. Princes Street was a very wide street, and had been paved in half widths only, but it was an instance

showing how, if sufficient time were given, excellent work could be turned out. Coming to the other side of the question, he knew an instance in the east end of London where the stones were laid upon fresh concrete. As fast as the concrete was thrown in place the stones were bedded, rammed, and grouted, and left four or five days. The man who did it told him that he considered it to be one of his best pieces of pavement, and he had laid many thousands of yards throughout London. That pavement was put down about twelve years ago, and to this day it maintained its surface splendidly. Now, passing to the question of macadam, he also cordially agreed with what Mr. Deacon had said upon that question. The state of the west end roads, both upon a hot July day, and also in muddy, dirty, rainy weather, was abominable. Mr. Aveling made some rather severe strictures upon macadamised roadmaking. He was fully aware of the difficulty owing to the largeness of the stones. Those who had had experience upon the matter would agree that for the last few years there had been much difficulty in getting the stones properly broken. Notwithstanding letter after letter, complaining of the large size, all the contractor said was: "The work is done in Guernsey, and we can only use our best endeavours to get them broken smaller." He believed, however, that the stone now being delivered in London was smaller and more satisfactory. With regard to macadamised roads, he found the average cost per yard of maintaining King's Road and Sloane Street, including cleansing, amounted to no less than 2*s.* 11*d.* per annum; but on one portion of that which was narrow it was no less than 6*s.* Of course the cost varied according to width and traffic. On the Chelsea embankment, where the roadway had been newly made upon a bed of concrete 12 inches thick, the cost was about 1*s.* 4*d.* per yard per annum; and in the side streets it varied from 9*d.* to about 1*s.* 6*d.* As Whitehall and Parliament Street had been referred to, he would state a few figures to give an idea of the cost of maintaining them. The cost for maintaining the macadamised roadway of Parliament Street, for 1877, was 2*s.* 9¾*d.* per yard; and for 1878, 3*s.* 1*d.* For Whitehall, for 1877, it was 2*s.* 10*d.*, and last year 3*s.* 2½*d.* In Great George Street the cost for the year 1877 was 3*s.*, and 1878 1*s.* 0¾*d.* Victoria Street cost, in 1877, 2*s.* 3*d.*, and last year 1*s.* 8*d.* per yard. That was without cleansing, which amounted to 10*d.* or 11*d.* per yard per annum in addition. The Vestry of Paddington, in May 1878, issued a valuable report upon the question, arriving at the conclusion that where a macadamised roadway cost 2*s.* per yard per annum, it was desirable

that some other pavement should be substituted; and they further went on to state, that that pavement should be wood. The question of wood paving had also been considered in the adjoining parish of St. George's, Hanover Square, and most successfully adopted. It had been adopted in Piccadilly and Knightsbridge, and was about to be laid in Bond Street and St. James's Street. That parish certainly took the lead in abolishing macadamised roadways, and great honour was due to them for substituting the existing clean, quiet, and convenient pavement in Piccadilly and elsewhere. There was another question with regard to cost. He was commencing a length of 2 miles of wood pavement in King's Road, Sloane Street, and Sloane Square, representing an area of more than 30,000 square yards, and costing nearly £18,000. Before going into that, he made exhaustive inquiries, and inspected the whole of the pavements laid in various parts of London. The conclusion arrived at was, that it was desirable to have a simple, but substantial, kind of pavement, and one that should be placed upon a bed of Portland cement concrete, 6 inches thick. The most satisfactory and simplest pavement that he had seen was a piece laid in the Fulham Road by the Cancer Hospital, and another in High Street, Kensington, by the Vestry Hall, laid by Messrs. Mowlem, Burt and Co. It consisted simply in laying ordinary deal blocks upon a concrete bed, grouting them in with a lime grout. Another piece, between Oxford Circus and Tottenham Court Road, was also done on the plain system, blocks being put upon the concrete and grouted in with Portland cement. That was laid very economically; but the joint was a little too wide. It was essential that the joint should be narrow, and that it should be carefully made, with a view of keeping it parallel and tight. The system he was adopting was similar to this, with plain blocks on a concrete bed; only, instead of using the ordinary strip between the blocks, he was fixing three little iron studs to each block, which would give the pavement a firmness before there was any grout upon it. The cost would be about 11*s.* 3*d.* per yard; and he estimated, that if the blocks of that pavement had to be renewed entirely every six years—not the concrete, because that was supposed to last many years—the cost at the end of fifteen years, including the cleansing, would only amount to 1*s.* 11*d.* per yard, whereas the cost of the macadam at that part was no less than 2*s.* 10*d.* That, he thought, would satisfactorily allay the fears expressed by Mr. Giles as to the long term of the contracts. It was not proposed to retain the existing blocks, but to renew them every six or seven years according to the requirement.

Mr. L. H. Isaacs, speaking of the durability of granite blocks, said he paved High Holborn in 1857, and the granite was only once turned in the course of twenty years. It was removed in 1877, and the stones were now being re-dressed, and would be re-laid in one of the second class streets of the district. Those granite cubes were 9 inches deep, and were placed on a bed of concrete 9 inches thick. When cubes 5 inches and 6 inches deep were mentioned he warned the younger members of the Institution not to be led away with the comparative cheapness of that class of paving, but to have the courage to insist in the first instance, if they were dealing with a leading thoroughfare, on having it paved in a thoroughly first-class manner with materials of an enduring character, being assured that they would ultimately receive the thanks of those for whom they were concerned for having so done. Any stint with reference to concrete foundation was parsimony of the worst kind. Certainly in no leading thoroughfare of the metropolis should a bed of concrete of less substance than 9 inches thick be thought of. He had known instances in which 12 inches had been employed; that was, in his opinion, somewhat in excess; but, if it were an error, it was on the right side. With regard to granite, experience had shown London engineers that no material had been brought into the London market, taking all circumstances into consideration, which had answered its purpose so well, both for endurance and the comparative absence of slipperiness, as Aberdeen granite. Though, of course, the authorities at Liverpool and Manchester would be unwise to turn their eyes away from the Welsh quarries, all his experience of the Welsh paving sets tried in London established the fact that, compared with Aberdeen, they were inferior; and therefore, again, the comparative smallness of their cost had to be counterbalanced by those other features of the case which must not be ignored. A few years ago he had occasion to cross over one of the Manchester streets which had been treated with grouting of asphalt or tar. It was a broiling hot day in the month of July or August, and he was particularly struck with the fact that the pavement was, so to speak, swimming. The asphalt grouting had given way under the sun's rays, and when he crossed the road it was in a measure like passing over birdlime. Whilst, therefore, asphalt grouting might be used for some descriptions of wooden pavement, for filling up one-half of the depth of the interstices between the blocks, the top being filled with the ordinary lime or Portland cement grout, the subjecting any one to the chance of walking over street pavements, and taking home on his boots that which

readily altered the pattern of his carpet, was, he ventured to submit, inexcusable. Mention had been made of wooden pavements which had been introduced, and stress had been laid upon one particular pavement, that of Henson's, of which there was a good specimen in Oxford Street. He frequently rode over 2 miles of wood pavement, commencing at the Marble Arch and terminating at Gray's Inn. He had taken note of the whole of the different systems employed along that line, and was of opinion that Henson's was not the best. That pavement was put down with simply a layer of felt between four of the courses, and every fifth course had a joint ½ inch in width. It was a remarkable fact, that unless everything in connection with a street pavement was homogeneous—unless it was treated in every way alike throughout its entire width and length, it would not wear evenly or well; and all attempts that had been made to introduce materials of different kinds in combination—iron and wood, stone and wood, as also the different modes of dealing with those pavements—invariably ended in failure. Already Henson's pavement was beginning to show marks of wear far earlier than the pavements on each side of it. He did not like to appear the advocate of any particular system, but, certainly, of all the descriptions of wood pavement which had as yet been submitted to trial, he thought that of the Asphaltic Wood Pavement Company had in it the elements which would ensure its wearing better and longer than any other, and as regarded ease of draught and security for horses, it left little or nothing to be desired. On the score of foothold, in his opinion each course of blocks should be separated from the other by a joint, certainly not less than ½ inch in width, because it was painful to see valuable horses sometimes struggling with a load a little heavier than they could conveniently move, missing their foothold and falling down. He also endorsed, with great pleasure, the remarks that the most splendid samples of stone pavements, ever yet submitted to the notice of mankind, were those to be found in the northern cities of Italy. Nothing could approximate to the luxury of riding along the streets of Milan, where these broad tramways of stone were laid down with granite sets in between. That was the pavement *par excellence*. In the Commercial Road East, he remembered a stone tram pavement had been laid down for the purposes of the St. Katharine and the East and West India Dock Company. It was a noticeable fact that whenever omnibuses or cabs, or indeed a private carriage, could manage to get out of its track and get on to that stone tram, they invariably did so. No better evidence could be afforded of the value of a pavement

than that of the driver, who always knew what best suited his vehicle, his horses, and the passengers he had to carry.

Mr. JOHN MOWLEM BURT said Mr. Rawlinson had been rather severe in his strictures on Whitehall and Parliament Street. He agreed that those roads were not an honour, but the reverse. There were, however, three or four things which tended to keep them as they were, and the Government had something to do with it; because, had they taken away that block of buildings constituting one side of Parliament Street, that street would have been much wider, and therefore more easily kept as a macadamised road, or it would have been paved with wood or stone. The parish had been kept upon tenter-hooks for a considerable time, and did not wish to spend money upon a narrow road if it was going to be widened. Besides that, the system upon which the parish worked was, he ventured to say, a bad one. The roads were under the charge of a surveyor so far as the material being put on; but the cleansing was let to a contractor, who was not responsible for the wear and tear of the road. The damage done to the macadamised road was in the morning, say from 8 A.M. to 10 A.M.; for when there was what was called a "licky" morning, the road was in rags in a quarter of an hour. The moisture in the atmosphere combined with the horse-dung, and so forth, worked it into a pasty state; the wheels stuck to the paste, the paste to the stones, and the stones were pulled out. The reason that a macadamised road cost so much was because it was not kept cleansed, for, if thoroughly cleansed, the cost of material would not be one-half of what it was at present. He said so because he thought it specially applicable to Parliament Street and Whitehall. A remark had been made that the mud came up through the material on to the surface. He disputed that fact, and would ask how the black mud from underneath could come up through solid macadam, where the layer of stones was 8 or 9 inches thick?

Mr. RAWLINSON said he meant that mud came up through paved roads with a bad foundation, not through macadam.

Mr. BURT agreed that it came up where there was no foundation on a paved road, but it did not do so on macadamised roads. The mud came from the surface, and it was ground up because the road was not kept sufficiently clean. With regard to 3-inch sets, in 1840 Blackfriars Bridge was first paved with sets 3 inches wide and 9 inches deep. Thirteen years and a half afterwards one of the arches gave way, and the stones had to be taken up, some being Guernsey and some Aberdeen. The Guernsey stones

were only worn down ¼ inch, while the Aberdeen stones were worn 1½ inch. When the old bridge was removed, about ten years ago, he was in charge of the men pulling up the stones, and found that many of the Guernsey stones were 8½ inches thick, while the Aberdeen were only 7 inches. Those stones were now lying in a good many London streets, and being run over. The Edgware Road was laid twenty-six years ago, with a 6-inch concrete foundation, and 6-inch granite cubes grouted with lime. That road was relaid the year before last at a cost, he supposed, of about 2*s.* a yard; so that in twenty-five years the Edgware Road had only cost the parish about 1*d.* per yard per annum. The western end of Oxford Street lasted longer than that, or something like twenty-eight years, showing that the cost of stone paving was considerably less than that mentioned as the cost of wood paving. With regard to wood paving, six or seven companies or individuals were running a race to see which could get ruined the fastest. Some contractors had been foolish enough to undertake the repair of wood-paved roads for seventeen years. He was thankful that the firm with which he was connected were only responsible for a small number of streets, and the fewer of them the better they would like it. They had undertaken to keep those roads in repair for seventeen years at 1*s.* per yard per annum. Mr. Stayton had stated that he was paving the King's Road for 11*s.* 2*d.* per yard, but he believed that when the job was completed the estimate would be exceeded. Wood paving was now cheaper than it was four or five years ago, and cheaper than it might be expected to be five or six years hence; and now was the time to do it cheaply, if at any time. He quite agreed with Mr. Stayton that the simpler the wood paving the better. Let 6 or 9 inches of Portland cement be laid down, and the blocks put on the concrete, and grouted in with lias lime.

Mr. DEACON, in reply, desired to refer further to the question of the units adopted in the tables attached to Mr. Howarth's Paper (page 48), and in the two tables in his own Paper (pages 23 and 24). He regretted that those units were not the same, but he saw no reason why they should not be made the same. Mr. Howarth's reason for not adopting the yard width per annum as a standard of traffic was, that the yard split the width up into fractions. That, however, was of no importance, because all that was necessary in order to reduce the figures to his units was to multiply them by 940, and that process could not produce fractions. If any of the traffics per foot per day mentioned by Mr. Howarth were multiplied by 940, his traffics per yard per annum would be obtained, very nearly.

His traffics were taken over the whole twenty-four hours. Sundays were in every case omitted, but for the streets in question that was of little importance. Mr. Howarth's mode of taking the traffic by half hours scarcely appeared to admit of sufficient accuracy. He doubted whether it was sufficient simply to sample the day, as it were, by half hours here and there. There was still a little misunderstanding as to his statements with respect to the amount and intensity of the traffic in Liverpool. It was true that in the text he had mentioned totals of 3,000,000 tons per annum, and so on; but he had in all cases reduced the traffic in the tables to standards of 100,000 and 40,000 tons respectively per yard width of carriageway per annum. At page 22 he had referred to a street in Liverpool, one of the first to receive the new class of pavement, which had been "subjected to a traffic of 218,000 tons per annum per yard of width, and a mean load of 0·679 ton per wheel, including empties," and which had "cost nothing to maintain beyond the occasional filling up of joints with asphalt, and the restoring of a few sets, not worn, but split and crushed by loads of 60 tons on four wheels." The statement as to weight had been questioned in two or three different quarters. It was literally correct, however; and in the last carriageway bridge constructed in Liverpool—a wrought-iron arch—although greatly limited in depth between the surface of the carriageway and the intrados of the arch, he had made the safe-load 60 tons on four wheels in addition to a crowd. He had a letter from Messrs. George Forrester and Co., marine engineers of Liverpool, which ran as follows: "We made six boilers for the 'Montana,' the weight of each being about 48 tons. Our boiler truck weighs about 11 tons, and has two wheels 4 feet 6 inches diameter, and two wheels 3 feet 3 inches diameter. The wheels are 10 inches broad, and are rounded about 1 inch over the tires. We have constantly sent down to the docks boilers from 40 to 45 tons weight on the same truck. We think the bulk of these boilers is also somewhat unusual for street traffic, and the number of horses attached; we have had, we believe, as many as thirty." Every one of these boilers passed over more than a mile of pavement, and in no single instance had the concrete been in the slightest degree damaged. True, when the wheel, the tire of which was rounded in cross section, got on to the projection of a set, that set was sometimes crushed, but the concrete below remained intact. The depth of concrete generally employed in Liverpool was 6 inches; and the fact that it had never given way appeared to him a complete answer to the objection made to that thickness as being insufficient. He spoke

only of the kind of concrete employed in Liverpool, the mode of preparing which had been fully explained at page 11. It had also been said that the kind of traffic had a great deal of influence upon pavements. Of course it had; and, with the object of showing that influence, he had stated the average number of tons per wheel, in every case including empties. Mr. Giles appeared to have assumed that the traffic had been measured merely by the number of vehicles, and that the statistics were therefore utterly unreliable. If the assumption were correct the conclusion would be correct also.

There was a misapprehension with regard to what he had said about the tilting of the sets. It was thought that he meant tilting by the horses' feet. The backward pressure of the horse's shoe always caused unstable sets to lie over laterally against the direction of the traffic; but the tilting to which he particularly referred, and for the prevention of which it was necessary that the depth of the set should bear a certain moderately large ratio to its length, was the kind of tilting or tendency to tilting that occurred when one end was pressed down under a heavy load. A great deal had been said about Aberdeen sets. He knew them well, and had used sets of similar granite to a large extent; but where such granite was laid on lines of thoroughfare parts of which were similarly paved with the metamorphic rocks and syenites of Wales, the wear of the Scotch granite sets was relatively so great that they had sometimes been removed before the Welsh sets were worn flat. He could not agree with Mr. Redman, that it was desirable to use Aberdeen granite sets 9 inches deep for heavy traffic, while the much harder and more durable Leicestershire granite, in cubes of 4 or 5 inches, was used for light carriage traffic. The latter might answer, but the former would certainly not be economical or durable. Mr. Redman thought a bed of 9 inches of concrete for heavy traffic and of 6 inches for light would make the best foundations, but that they were inadmissible in London, where the frequent disruption of the pavement for pipe and telegraph laying necessitated constant repairs and precluded the possibility of arriving at a perfect pavement. A large experience of the use of concrete led Mr. Deacon to an exactly opposite conclusion. His practice and its results were fully explained at page 9 of the Paper, to which he might add, that leakages from pipes beneath concrete were much less frequent than when the pipes were subject to irregular subsidence, due to the percolation of water and to traffic.

One of the most important points which arose in the discussion related to the wear of wood pavements. Mr. Howarth gave the

traffic in Oxford Street as 300 tons per foot per day, equal to about 280,000 tons per yard per annum, and the wear as only from $\frac{1}{8}$ to $\frac{1}{16}$ inch in three and a half years. Bold Street, in Liverpool, reduced to the same traffic and time, had a wear of $1\frac{3}{8}$ inch. Church Street, which was paved with Mr. Howarth's pavement, had a wear, reduced to the same traffic and the same time, of $1\frac{5}{8}$ inch. Great Howard Street, Liverpool, reduced to the same traffic and time, had a wear of $2\frac{5}{16}$ inches, the excess in this case being due, no doubt, to the greater intensity of the traffic, viz., ·77 ton per wheel, including empties. Mr. Howarth, upon the basis of this $\frac{1}{8}$ to $\frac{1}{16}$ inch, proposed a duration of twenty-five years for every inch in depth under similar traffic, "if it were possible to assume an absolutely uniform quality of wood fibre;" but, judging by experience in Liverpool, the duration for the same amount of traffic would be much shorter.[1]

It was curious to compare Mr. Howarth's statement as to the wear of wood pavements with those of Mr. Elwes and Mr. Woulfe Brenan, both of whom had had experience of wood paving. Mr. Elwes "scarcely went so far as Mr. Howarth in estimating the wear as only 1 inch in twenty-five years, but he thought under ordinary circumstances it would not exceed $\frac{1}{8}$ inch in a year"—that was 1 inch in eight years; while Mr. Brenan had come to the conclusion that after five years provision should be made for the complete relaying of the road; which he supposed meant a wear of 1 inch

[1] Since the discussion took place Mr. Deacon has had an opportunity of reading Mr. Howarth's reply. In the Paper (p. 44) Mr. Howarth said the Oxford Street blocks were originally 5 inches in depth. In his reply, however, he said they were "5⅞ inches, not 6 inches," and that Mr. Deacon did not allow ¼ inch for compression. When Mr. Howarth exhibited blocks, which, in order to show the wear correctly, required very accurate measurement, it was unfortunate that the original depth was not given correctly, and that it had to be subsequently altered; 4⅞ inches or 5⅞ inches, whichever Mr. Howarth meant, was an unusual depth. The saw-cut would not nearly account for it. Mr. Howarth was mistaken, moreover, in supposing that ¼ inch had not been allowed for compression. Mr. Deacon knew that Wood Pavement Companies were in the habit of making this allowance, and although he considered it too much, it had been made. But Mr. Howarth had stated that "$\frac{1}{16}$ to $\frac{1}{8}$ of an inch is the utmost amount of wear shown by any blocks from the same position." He had carefully measured the blocks exhibited, and thought that, even after allowing all the deductions asked for, the wear was considerably more than this. The whole of the timber used in Liverpool had been selected with the greatest care. The measurements of blocks were made periodically, and the traffic was ascertained in a manner which he thought was not open to objection. The results of different wood pavements reduced to the same units, confirmed each other, and he was obliged therefore to conclude that the discrepancy was to be found either in the measurement of the Oxford Street blocks or in the traffic, or probably in both.—G. F. D.

in less than five years. But as neither of these gentlemen had stated the traffic per unit of width upon which the estimates were based, their experience so far as given could not be usefully applied. Surely such subjects were capable of being dealt with in a more exact manner than this. Mr. Brenan had said that the maintenance (for seventeen years) required in the contracts for wood paving with the city of London, was absurdly large, and that every one must know that wood pavement would not last for that period. If, in entering upon their contracts, the companies had not considered the cost of occasional renewals, they had certainly made bad bargains; for the Liverpool contracts and, as he believed, those of London, required the pavement to be left in perfect condition at the end of the term. But as a matter of fact the prices charged by the companies per annum greatly exceeded the cost of maintenance proper, and left a large margin for renewals. Thus, the companies' charges in Liverpool were 1*s.* 6*d.* per square yard in one case, and 1*s.* per square yard in another, while the actual cost of simple maintenance, under a traffic of 100,000 tons per yard width per annum, was shown in the table on page 24 to be only 1*d.*, though by the same table the sinking fund required was 10*d.* per yard per annum.

With reference to the necessary depth of wooden blocks, he agreed in principle with the suggestion that the surface of a roadway should be treated as a veneer subject to wear, laid upon a permanent foundation not subject to wear; but he did not agree with the conclusions drawn with reference to the desirability of using very shallow blocks. A depth of 5 inches would give a sufficient life to the blocks if the traffic did not much exceed 100,000 tons per yard width per annum; but a depth of 4 inches would, in practice, leave only about 1 inch for wear, which gave a very short life. Blocks 6 inches thick had been worn too thin for use in four years, under a traffic of 300,000 tons per yard per annum. Doubtless if the blocks could be fastened to the foundation in a perfectly stable manner, their depth could be reduced, and some economy of first cost would result. Concrete foundations for wood pavements had been objected to by Dr. Paget Higgs, on the ground that "the constant shrinking and swelling of the wood would always create spaces through which water would percolate into the lower part, and he could not conceive how, in the case of concrete or asphalt, it could get away." Mr. Deacon had satisfied himself that such shrinking and swelling as occurred were incompetent to create spaces through which water could percolate. Possibly, with imperfect pavements, or if pools of water were left

on the pavements, such percolation would take place at certain points; but where, as in Liverpool, the smooth, close-jointed wooden blocks threw the water off readily, it certainly did not penetrate. In supposing that he claimed for bituminous concrete even half the credit of the stability of Henson's wood pavement in Liverpool, Mr. Elwes had been mistaken. He referred to concrete generally, whether cement, lime, or bituminous, provided only that the surface was smooth. The bituminous concrete was convenient on account of the fact that it could be used immediately after being laid, but the same stability of the surface blocks would probably be produced with any perfectly smooth and unyielding foundation.

Another speaker on behalf of a wood pavement company was Mr. Copland, who made comparisons with defective stone pavements, in which "water percolated through the surface," and in which there were "irregularities in the quality of the concrete," with the result that "the road was soon destroyed": this, he submitted, was not useful controversy. There were bad stone and bad wood pavements. The only fair method of comparison was to assume good work in both cases, and then to compare the results.

He believed that he had placed wood pavement before the members in the best possible light as to cost and other qualities—in a better light, indeed, than that in which it had generally been viewed. Wood pavement possessed some excellent qualities, preeminently that of noiselessness; and as the sanitary difficulty was practically removed by creosoting, and by preventing the fibres from spreading, as explained at page 30, he believed its use would be greatly extended. On this account he had been at considerable pains to ascertain the wear and consequent annual cost; for if the wear and the annual cost were found to be in excess of the statements put forth, he feared a revulsion of feeling would follow against the pavement.

He could not concur with Mr. Aveling, in thinking that he had treated macadam hardly. He had given macadam its proper place in suburban and country roads of little traffic. He agreed that macadam was not often laid and maintained in the best manner; but however well laid and maintained, it could not be otherwise than an expensive, dirty, and undesirable pavement for streets of much traffic. He felt very strongly the truth of his remarks with respect to London macadam pavements, and was glad to hear Mr. Rawlinson allude to them in equally strong terms. Mr. Rawlinson had referred particularly to Parliament Street, the

main thoroughfare to the Houses of Parliament. Mr. Deacon had avoided mentioning names, but this street was one of those uppermost in his mind at the time.

A section of his Paper was devoted to the camber of carriageways. The subject was of great importance, and he regretted that it had not been more fully referred to. Mr. Haddan had indeed asked "why should not the fact be accepted at once, that with the increased width of streets, the corresponding camber for obtaining proper surface drainage was impossible," and "a system of perfectly level paving (might) be adopted, with free down drainage between the joints to an impervious substratum cambered to an extent necessary to ensure perfect drainage?" This was the antithesis of an impervious pavement with a vengeance. No doubt the suggestion arose from the malformation of the cross section of many wide streets, for which it seemed to have been assumed that the segment of a circle was the right figure, so that a great versed sine was necessary in order to provide sufficient fall for water near the crown. This, however, was a mistake, and he had endeavoured to show (page 19) that the section should be approximately hyperbolic. When the rules he had there given were adopted, it would be found that the cross inclination would not be any greater in a wide than in a narrow street, and that the water would be thrown off equally well in both.

His attention had been directed by Mr. Price-Williams to the fact that no note had been attached to the tables explaining that the cost of the concrete foundation should be deducted from the capital sum before the sinking fund was calculated, and that the value of old materials was deducted from the cost of renewal. An explanatory column had now been added to the tables, in accordance with this suggestion.

Much had been said as to the desirability of grouting stone sets with Portland cement. There could be no doubt that, where there was a good concrete foundation, this grouting made a stable and durable pavement. But he was satisfied, having tried both methods, that it was not so desirable as the bituminous method when the sets had to be removed for gas or water purposes. It was impossible to raise sets properly grouted with cement without breaking them; whereas, with asphalt, the first few could be drawn out with a properly made tool. Moreover, there was a little elasticity in the asphalt joints which diminished the noise.

It had been stated that damage to the paved streets of Manchester had been done by the late frost to the extent of £12,000. He should like to hear Mr. Lynde's explanation of this. No doubt

if water did get in between the sets of pavements intended to be impervious, and could not drain freely away, a hard frost would cause extensive disintegration. Happily, no such difficulty had arisen in Liverpool; but he thought it necessary to watch an asphalt-jointed pavement for the first year of its life, and to fill up any joints which showed signs of opening, owing to the further sinking of the asphalt, or to its disintegration in a few places where the composition was too brittle, which sometimes happened when the few last bucketsful left in the boiler had been used.

The question had been asked by Mr. Edwin Chadwick if he had employed a dynamometer for the measurement of traction on carriageways. As stated in the Paper, he had considered the desirability of doing so, but before taking further steps, he consulted all the records he could find of the results that had been brought out by dynamometers, and, amongst others, those in the 'Journal of the Society of Arts,' and it turned out, as he expected, that the results were often inconsistent with experience. The reason was obvious. The facility with which a horse drew his load was not only proportional to the smallness of the load and to the smoothness of the pavement, but also to the facility with which he trod the ground, and felt his footing. It was not necessary that the roads should have wide joints, or that they should be very rough; but they should be slightly rough; and in this respect he believed that in Liverpool very satisfactory results had been attained, as was shown by the fact that there had been a saving of more than £10,000 a year in cartage on every mile of the dock line of streets since the present roadway had been laid down. Dynamometers were desirable if the results they gave were qualified by reference to the work a given horse could perform on various classes of pavement; but without such qualification, those results were apt to mislead.

Mr. HOWARTH, in reply, said, the principal point to which he wished to refer was the futility of endeavouring to compare the traffics on different pavements without some figures upon which the comparison could be based. It was impossible to lay one town beside another, or one street beside another, and say, "The wear is so much on this street, and so much on the other, and thus compare the traffic of the different streets. Slight differences in the amount of traffic were cumulative. If it were assumed that a certain street had a traffic of 100 tons per foot wide per day, which was the standard he had taken, and the street was 30 feet wide, that would give 3,000 tons, over the pavement, per day of ten hours. If another street had a traffic of 110 tons per foot, or 3,300 tons per day, there

would be a difference of 300 tons per day, or 90,000 tons per year. That difference would be a very large traffic over a country road; yet such expressions were constantly used as, "Probably the severest traffic in London." It was absurd to make contrasts in that way. He was afraid traffic was still estimated by how long any pavement was likely to last. A question had been asked about the system of half-hour observations. Half-an-hour was, as a matter of fact, the outside time during which any man could be trusted to take an observation in a street where he had to note the character of every vehicle, form an approximation as to its weight, and also keep a careful account of the numbers. He had done this himself, and he thought it was the hardest work he had ever done in his life. If every half-hour of the day was identified so that it could be known again, each would be a record in itself, and the aggregate value could be reckoned afterwards. For instance, if the half hour from 8 to 8·30 were called A; and from 8·30 to 9, B; and observations were taken in that way; then, after a term of years, there would be a continued record of traffic observations for the whole day. Mr. Aveling had made a sturdy and able defence of macadam. He did not suppose that anyone doubted that macadam could be well laid or badly laid; but how long would the best macadam road that could be laid last with a traffic of 450 tons per foot wide per day? That was his test. A good deal had been said about simple wood pavement. He maintained that a wood pavement should be simplicity itself. If it were not, there were necessarily objections to it. He had instanced Henson's as the simplest he had seen. Only one material was used besides wood, setting aside the concrete foundation, and that material, instead of being sand or cement, was impervious, elastic, and did not allow the water to pass down. One or two questions had been asked by Mr. Deacon and others with reference to the wear and tear of wood. Whereas he had stated that in three years the wear on a certain length of pavement was under $\frac{1}{8}$ inch, Mr. Deacon showed it by measurement to be under $\frac{3}{8}$ inch. The explanation was, that Mr. Deacon, first of all, was not aware that the original depth of the blocks was $5\frac{7}{8}$ inches, not 6 inches; and, secondly, did not appear to make his own allowance of $\frac{1}{8}$ inch for compression, which took place very early. The wear was therefore reduced to the figure he had mentioned. Another misconception, with regard to the twenty-five years, arose, he thought, solely from the fact that one or two gentlemen had read only half the sentence in the Paper. What he had stated was, assuming the wear was $\frac{1}{8}$ inch in three years, and that the rate was the same all through, that the wear would

be $1\frac{1}{8}$ inch in twenty-five years; but he went on to explain why, practically, such a condition never arose. This appeared to be lost sight of. He never claimed that, under ordinary circumstances of heavy traffic, wood could be made to last twenty-five years. He quite agreed with what Mr. Elwes had said about the depths of the sets. It was a mistake to put very deep sets of either wood or stone. As a matter of fact, the surface of wood became uneven long before the depth was worn out. He thought a 5-inch, or occasionally even a 4-inch set, was quite as good for purposes of wear as 6-inch or 7-inch sets. Two corrections were called for by the remarks of Mr. Isaacs, which Mr. Howarth had listened to with surprise as coming from a gentleman to whom the details of wood paving had been an object of study. The first was that the Henson paving was apparently laid with an open joint at intervals. It was scarcely necessary to observe that this was not the case, as the whole purpose and value of the close joint would be defeated by such a construction. The appearance which led Mr. Isaacs into the mistake was that of the grooved block at every fourth course; inserted at one time as an apology for foothold, because it was impossible to get the uniform surface accepted without it; but it was now being abandoned. The other point was Mr. Isaacs' remark that the Henson pavement in Oxford Street was showing signs of wear "far earlier than the other specimens of wood paving adjoining it." Had Mr. Isaacs made inquiry into the facts of the case, he would have ascertained that not only was the pavement in question laid down a year and a half before any of the other systems near it, but that one of these latter had been entirely relaid within two years of use. One or two remarks had been made about concrete foundations which rather surprised him. It was said that water filtered through the wood, collected on the concrete, and disintegrated it; but surely no engineer would maintain that the presence of water disintegrated a good Portland cement concrete. As regarded that infiltration through wood, he thought it had been proved that such a thing did not take place in a really tight-jointed pavement to such an extent as to be detrimental to it; and he showed blocks that had been down four or five years, and mentioned others that had been down a still longer period, and when they were split in two it was found that the absorption was absolutely nil. He considered that the theory of the absorption of putrescent matter into a properly-laid wood pavement was neither more nor less than a bugbear, arising out of the use of open-jointed pavements. At present the cost of wood pavement was to a certain extent

compromised by the sharp competition that existed. Some gentlemen had put it very plainly, and said that several companies were running a race to see who could be ruined soonest. He believed that this was by no means unlikely; but pending that contest, he might give the actual cost at which the close-jointed pavement was laid down. Wood of such a kind as ought reasonably to be used for the purpose, red deal, of good quality, 6 inches deep, would cost 5*s.* 6*d.* per superficial yard; the felt for the tight joint 6*d.* per superficial yard; the concrete—Portland cement and clean ballast (6 to 1), 6 inches deep, 2*s.* 6*d.* per superficial yard; labour, watching, lighting, and all extras, and dressing of fine grit and tar, 3*s.* per yard; making a total of 11*s.* 6*d.* per superficial yard. He believed that to be a minimum price at which a thoroughly sound and satisfactory close-jointed wood pavement could be laid.

In looking back on the general tenour of the discussion, he would do no more than remind the members of the remarks made by Mr. Rawlinson, which were independent and impartial, and by a gentleman who had not claimed the subject as a specialty. Every one in the room must have been impressed, as he himself was, with the fact that those remarks were characterised by the strictest scientific accuracy and truth. It was impossible that any person who had only casually observed pavements could have been more correct. At the close of this discussion he could not put the whole problem in a clearer manner than Mr. Rawlinson did at the beginning, but he would sum up the needs of wood pavement in the following words: Foundation absolutely solid and rigid, impervious to water if practicable, and up to the extreme weight it could ever have to carry; superstructure of some material in the use of which the questions of first cost and maintenance were reasonably balanced; slight elasticity in the pavement somewhere; but at the right place, and that right place not the foundation. The question then remained, whether or not the luxury of noiselessness, ease to the horses, and surface elasticity, were demanded. If that luxury was to be had, must it be paid for or not? He thought the practice of the present day showed that that luxury was really afforded by close-jointed wood with a concrete foundation, as compared with granite with equal care bestowed upon it, for nothing.

Mr. Rawlinson, C.B., said, he did not know whether in the discussion the element of speed had been much considered. In reality it was speed which was the prime wearing power on any road or pavement. A light, quick traffic was more destructive to a road than a heavy, slow traffic; for a wheel, after it got up to a speed

of 5 or 6 miles an hour, ceased to roll, and went by a series of jumps, as any person who watched it might notice. That caused a tendency in every kind of road to become corduroy, and therefore the pavement or road surface which by smoothness offered the least resistance to the wheel, which would give the securest foothold, and continue smooth and even the longest, whatever its first cost might be, even though it were double what Mr. Howarth had mentioned, would be the cheapest to the rate-paying community and to those who used the street or road. It was not the first cost that was the chief thing to be considered in road making, but which road would wear the smoothest under the traffic that passed over it; and in a place like the metropolis that traffic was almost necessarily a quick one, which, as stated, was the most destructive to any road. After all the steam rolling and pressing down, a macadam road in London, subjected to a few hours' wear in wet weather, became a mass of mud, while a few hours of dry weather made it dust. The subject of machines for road making had been brought before him by a question put by the Foreign Secretary, as to the best mode of cleansing roads (the information being required by the Municipality of New Orleans); and he had collected, from the different makers of implements, catalogues of their machines, and copies of them had been placed in the library. If other persons were as ignorant of these new machines as he was, those catalogues would give them some information.

Mr. ELLICE-CLARK said, through the Secretary, that the Author of the Paper on Street Carriageway Pavements had principally confined his remarks to carriageways of hammer-dressed stone, with a short dissertation on those paved with wood. The mode of jointing granite sets by the use of lime grout was questioned, the Author stating that when this method was adopted the sets became loose. This might be so when little care was exercised in grouting-in the joints; but many acres of pavements thus jointed had been recently taken up in London, the stones being rigid in the positions in which they were first laid, excepting where they had sunk from openings for gas and water pipes; and at this moment many acres might be seen *in sitú* where the stones were rigid, erect, and the joints impervious. On the other hand, the method of jointing described by Mr. Deacon required greater care in execution than any other; the pitch and creosote needed mixing and boiling to a nicety; if insufficient oil was put, or the mixture was overdone, it became brittle, and *vice versâ*. During very hot

weather this asphaltic compound might be seen exuding.[1] The sets, in consequence, were displaced by the traffic, and the roadway "went to pieces." Looking at the areas paved, respectively (during the past twenty years), with lime-grout joints and pitch joints, the deduction of the Author in favour of the latter method was questionable; the experience of London engineers proved that, where the grouting was good, nothing could be better. With regard to foundations, experience had demonstrated that all carriageway pavements with blocks required a foundation of concrete. In Manchester, the method of having a foundation of cinders from 12 to 15 inches in depth, ground down by the street traffic, had been practised for many years, and was still upheld by the city engineer; but on examination of the streets paved without a concrete foundation, and those with, where the burden borne was equal, the Manchester method would not compare for durability with the other. The difference in cost was not much. Sets 6 inches to 7 inches deep, 3 to 3¾ inches wide, and 5 to 7 inches in length, cost 11*s.* per yard in Manchester, without a foundation; the 15 inches of cinders would cost 6*d.* more, making the total cost 11*s.* 6*d.* The same description of pavement, with a cement concrete foundation 5 inches in thickness, in Liverpool costs 12*s.* 6*d.* per yard. In London, the latter class of work would cost 16*s.* per yard; without concrete, 14*s.* a yard. The costs of paving laid in Liverpool did not compare favourably with those of London. Mr. Deacon gave 11·45*d.* as the cost per square yard per annum of a first class pavement set—concrete foundations, asphalt joints, sets 7¼ inches deep and 3 inches wide, per 100,000 tons per yard of width per annum. Cheapside, laid with sets 9 inches deep, 3 inches in width, the load reduced to the same standard, did not cost 8*d.* From the returns of Mr. Haywood, the city engineer, the cost of the granite pavements in the Poultry and in other streets were all less than the figures given for Liverpool by Mr. Deacon; indeed, none of the pavements in the city of London laid with grouted joints, the sets being 9 inches in depth, were so expensive as the pavements with asphalt joints, the sets being 7 inches in depth. It was difficult to obtain exact figures as to the weight borne by a road during its life; but certainly the statements, that 360,000 tons per yard of width per annum, with an average of 0·923 ton per wheel, were not surpassed, must be challenged. The average traffic of Cheapside was 16,000 vehicles per day; putting

[1] 'Royle on the Street Pavements of Manchester,' p. 56, vol. iii., "Proceedings of the Association of Municipal and Sanitary Engineers and Surveyors."

the weight at 1 ton for each vehicle, the result was 400,800 tons per yard of width, exclusive of Sunday traffic. He was of opinion that, for heavy traffic, sets 9 inches in depth, 9 inches in length, and 3 inches in width, laid on a bed of 12 inches of concrete, the joints grouted in with lime, formed the most economical method that could be adopted.

But little attention had been devoted by Mr. Deacon to asphalts. Putting aside the question of slipperiness, which had been decided in favour of asphalt against granite cubes; the maintenance of Cheapside, with its 400,000 tons per yard of width, cost 2*s*. 4½*d*. per yard, including sinking fund = 7·1*d*. reduced to the standard of 100,000 tons per yard of width. The advantages of asphalt pavements had been frequently pointed out; certainly not the least important to a town having so much of the carrying trade as Liverpool, would be the fact that since Cheapside was paved with Val de Travers rock asphalt, in December 1870, it had never been closed; and as the repairs were made between 6 A.M. and 9 A.M., when the omnibus traffic commenced, if the factor of cost were put aside altogether it would be worth while trying a pavement of this kind in the line of docks, where the gradients were flat. With regard to macadam, the Author's statements could be borne out by every engineer who had observed its behaviour under heavy traffic. The costs of maintaining some of the streets at the west end of London were as follows, the traffic being very small as compared with Cheapside:

	Width of Carriageway.	Cost per annum per sq. yd.
	Feet. Ins.	*s*. *d*.
Park Lane	51 0	3 6
Knightsbridge	75 3	3 6
Grosvenor Place	51 2	3 0
Buckingham Palace Road .	39 0	3 0
Piccadilly	46 0	4*s*. to 6*s*.

From observations made by him some time ago he came to the conclusion, that a carriageway 14 yards in width, having 15,000 tons per annum per yard of width, would cost about the same sum per annum whether paved or macadamised; therefore any street having a greater burden than this to bear should be paved. When macadam was used, it should be broken by hand to a 1¾-inch gauge, and rolled-in without any binding material. From observations made on roads where binding had been used and dispensed with, he was of opinion that the decadence of macadamised roads began with the use of binding material. The interstices on a square yard of road, from a great number measured,

rolled without binding, were 11 per cent. of the whole; the interstices of a road rolled with binding material freely used, were 33 per cent. of the whole. It was obvious that the greater the exposed area of stone, the longer the road must last.

Mr. DEACON felt bound to refer to the singular inaccuracy of Mr. Ellice-Clark's communication. It was said, for example, that the stone pavement of Cheapside (London), reduced to a traffic of 100,000 tons per yard width per annum, did not cost 8*d.* per yard per annum, and this had been compared with the 11·45*d.* which was the cost of the best Liverpool pavements. If Mr. Ellice-Clark had given due attention to the Paper, and to the report of Mr. Haywood, he would have found that the Liverpool figure of 11·45*d.* included interest on original cost, sinking fund, scavenging, and gravelling, while in the London figure of 8*d.* not one of these items was included. The interest alone on the first cost of the London pavement, with foundation, was more than the total cost per annum which Mr. Ellice-Clark had assigned to it. If account had been taken of interest, sinking fund, and scavenging, it would have been found that, instead of the annual cost of the granite pavements of the Poultry and other streets being all less than the figures given for Liverpool, they would in each case have been considerably more. A careful reading of the text of Mr. Haywood's report would show that the figures were simply the first cost, divided by the probable duration of the pavement in each case, and that they could not therefore be compared in any with Mr. Deacon's figures. Mr. Ellice-Clark's observations with respect to the relative traffic were equally fallacious; and his opinion as to the size of sets, and the thickness of concrete which "formed the most economical method that could be adopted," asserted without giving a single reason, would probably be classed among other hastily recorded conclusions.

Mr. W. CLARK observed, through the Secretary, that in 1854, as Surveyor to the Board of Health, he had charge of the street surfaces of Hull, then, with a trifling exception, entirely paved with cobble stones. Whitefriargate was the principal shop street in the town, and close to the docks; the traffic in this street, which was not a wide one, was very heavy, and it was determined to improve it. He sought for the best examples of street paving in England, and found them, as he thought, in Manchester, which was, and still continued he believed, the best paved town in this country; there street surfaces of asphalt concrete had been adopted, such as were described in the Paper. The Penmaenmawr sets were used for the best streets, and the interstices were first filled with shingle or stone chippings, and afterwards flushed with melted

pitch softened with tar oil. He carried out the same arrangement for the Hull street, first making a good foundation. This was formed with blocks of chalk laid on the clay, chalk being the cheapest material procurable; the interstices between the rough blocks of chalk were filled with smaller pieces, and the whole covered with Spurn gravel. The depth would be from 15 to 18 inches. This was well rolled with a heavy roller, and the traffic allowed to pass over it for about three months, during which the surface was kept up to nearly the level, and of the precise form required for that of the sets when laid. A very good foundation was thus formed, similar, in fact, to a macadam road, and on it the sets were placed, with a thin layer of sharp sand intervening. The stones used were 3½ inches wide and 7 inches deep; they were rammed, and the interstices, about ½ inch wide, filled with shingle and asphalt precisely in the way described in Mr. Deacon's Paper. He had seen the street in 1875, twenty-one years after its formation, and its appearance had but slightly changed; there was no reason why it should not have lasted another twenty years. On inquiry, he found that the only repair it had received was the occasional filling up of the interstices with shingle and pitch; it was said to be a little slippery, but it had undoubtedly been a very economical work, as its first cost was under 14*s.* per square yard. Probably the secret of its endurance in good form was due in a great measure to the fact that he had induced the authorities to duplicate the gas and water pipes, one of each being placed under the two footways, and the pavement had not been subject to disturbance.

At the time he spoke of, 1875, this pavement was about to be replaced by wood, entirely on account of the noise, and the tax-payers would in future be required to pay about 2*s.* per square yard per annum for the luxury of a quiet street. He considered Mr. Deacon's Paper to be one of great practical value. The subject was one which received but little notice, except from those who were in daily contact with it; and those who were so, knew how much the general appearance of an irregularly constructed crooked street might be influenced by a careful and judicious alignment of the kerb stones to the footways, the form and level of the carriage road, and their relative proportions as to width. It was the rule of the late Mr. James Newlands, of Liverpool, to make the footways each one-fifth of the entire width of the street; and the carriage-ways he preferred to make multiples of 8 feet in width for streets where there was any considerable amount of fast traffic, that being a convenient width for a carriage moving quickly. Thus two

carriages moving quickly could pass each other in 16 feet, and it required 24 feet for three carriages to do the same. Of course these rules would be varied where special circumstances rendered it necessary. Mr. Deacon had been rather hard on macadam pavement, and had shown that in Liverpool it was, of all descriptions, the most costly, viz., 2*s.* 11¼*d.* per yard per annum, with a standard traffic of 100,000 tons per annum per yard in width. When applied to Liverpool, and some other large towns, possibly it was so; but the cost was entirely due to the facilities or otherwise for obtaining materials of good quality. Thus at Hull the cost of sets stones was high, owing to the freight to be paid upon them; in Liverpool this was considerably less. At Hull the materials for macadam roads, when he had charge, were very cheap, in the form of gravel and boulder stones from Spurn Point. He thought, therefore, Mr. Deacon's table could not be taken as a guide in all cases. Moreover, since the introduction of the steam roller considerable economy had been effected in the repair and maintenance of macadam roads, the saving in material alone being variously estimated at from 20 to 50 per cent; and when it was considered that the cost of macadam roads was usually but one-third of either stone sets or wood paving, it was probable that it would continue to be generally used. When Victoria Street, Westminster, was formed, about twenty-five years ago, he thought he was correct in saying that even horse rollers were not in use on the macadam roads of the metropolis; certainly they were not generally used. The plan then was to consolidate the road by the traffic, and not to prepare it for the traffic. Some country towns were before the metropolis in this improvement. In India he found, as early as 1855, bullock rollers in general use for consolidating the street surfaces of Calcutta. It was the cruelty and difficulty of this operation, where bullocks were used, which first suggested to him the use of steam for the purpose; and the first steam road-roller was made to his order, under the direction of his friend Mr. Batho, by Messrs. Worsdell of Birmingham, and was sent out to India in 1864. The same machine had recently come into general use, as manufactured by Messrs. Aveling and Porter, who became sole licensees under Messrs. Clark and Batho's patent, and over one hundred steam rollers were now working in various parts of the world. With more experience in the formation of foundations and the materials used, together with the mode of rolling the surfaces, there could be little doubt that good and comparatively cheap roads would long continue to perpetuate the familiar name of Macadam.

Mr. G. F. LYSTER remarked, through the Secretary, that the system of concrete foundations with asphalt-jointed sets, as laid by Mr. Deacon in Liverpool, could not, in his judgment, be surpassed. The fact of the almost continuous stream of the heaviest class of loads passing over it, without its giving any appreciable signs of wear or inequality, proved conclusively to his mind, not only the excellent character of the work and materials, but also the general suitability of the design for the special traffic which it had to carry. It was difficult, if not impossible, to arrive at reliable conclusions as to the saving effected in the cost of traction, or from the wear and tear of carts, horse-flesh, &c., in their passage over such roadways as now existed, as compared with the older class of pavements, but it must be undoubtedly great, while, at the same time, the cost and infrequency of repairs must, from the character of the work, be proportionately small.

Mr. JOSEPH MITCHELL observed, through the Secretary, that he had given many years' attention to the repairs of the surfaces of roads and streets, and had watched with much interest the various new plans now being carried out. Wood paving had been laid in Lombard Street thirty years ago in hexagons, and had been taken up about twenty years afterwards. It had also been a failure in New York, and had to be taken up. Although pleasant to travel over, wood pavement was objectionable on sanitary grounds, and by reason of its cost. In his opinion the best pavement consisted of a foundation of concrete 6 to 8 inches thick, supporting granite sets 2½ or 3 inches wide, 7 or 8 inches long, and 7 to 8 inches deep, the joints being run with cement grout. He had laid a specimen on George the IV. bridge, Edinburgh, sixteen years ago, and it was now perfect, never having been repaired. The centre of George Street had been similarly treated; and Prince's Street, the chief thoroughfare in Edinburgh, was now being paved after the same fashion. He was convinced that, for secondary streets, concrete alone, if properly laid, would make a perfect and durable road; but, with the cement hardening so quickly, it required careful manipulation. It might be crushed into shape by the steam roller, or be cast in squares of 3 feet, allowed time to harden and consolidate, and then be carefully laid. But, of course, further experiment would be needed to work out the problem satisfactorily. A concrete road alone was almost as quiet as wood.

Mr. E. P. NORTH, of New York, remarked, through the Secretary, that while the pavements in London and in Paris were, in the stability of their construction, and their fitness for the purposes

intended to be served, far in advance of those in America, the best-made macadam roads were not as thoroughly built as roads of the same class in the United States. A visit of rather less than two months had given him few opportunities for judging of the climate and other influences to which roads were subject; but he had been strongly impressed with the idea that macadam, put down by the American method, would be free from many of the serious objections urged against such wheelways in England generally. The practice in the vicinity of New York was to lay down a course of 2½-inch trap, which was rolled until the stones were compacted, or showed a tendency to move on one another, when coarse screenings were added, consisting of the fragments of stone and dust that passed through 1-inch or 1¼-inch holes in the revolving screens used to size the stones after breaking. After this a layer of 1½-inch or 2-inch stones was added, which was rolled with screenings in the same manner as the first course. Fine screenings, or stone-dust, was then applied, and rolled in until every interstice became filled, and a layer of dust, say ¼ inch, remained on the surface. The road was then copiously sprinkled directly in front of the roller, until a wave of water was pushed in front of the wheels, and the surface behind them was mottled and "puddled." If the work had been skilfully and thoroughly done, the screenings (30 to 40 per cent. of the road) would have kept the angles of the stones from wear during rolling, and puddling would make the surface nearly impervious to water; so that in the climate of New York the road bed was only affected by frost coming out of the ground and by long-continued dry weather, when the larger stones on the surface were liable to be kicked loose by the horses' feet. There was also a difference in the amount of rolling given to American roads as contrasted with those of London and Paris. It was stated, in the notice of the objects, &c., exhibited by the city of Paris in the Exhibition of 1878[1] (page 108), that from 2·99 to 3·78 ton-miles per cubic yard were given to the streets of that city. In November 1878 the wheelway of Victoria Embankment seemed to be rolled but little more than the macadam of Paris. In America about 5 ton-miles per cubic yard were thought necessary; and in his experience the road was less liable to have loose stones on it, and opened less on thawing, when the rolling had been most thoroughly done. The maximum weight on the driving wheels of

[1] "Exposition Universelle de 1878. Notice sur les objets et documents exposés par les divers services de la Ville de Paris et du Département de la Seine." 8vo. Paris, 1878.

the rollers was 460 lbs. per inch run, and probably a heavier weight would be advantageous, at least for puddling. The wear of these roads was very satisfactory; the average cost of maintenance in the city of New York per square yard per annum having been $0·04\frac{1}{2}$ ($4\frac{5}{10}$ cents). Sixth Avenue, which was built in 1872–73, had recently been carefully cross-sectioned between 123rd and 124th Streets, where no broken stone had been put on since its construction, and the average wear at the crown was found to be 0·15 foot. This avenue had been sprinkled through the summer, and occasionally lightly spread with fine gravel, to keep the stones from being kicked out in dry weather. During the past year it had received a coating $\frac{3}{8}$ inch thick, consisting of two-thirds sand and one-third strong clay. No count of the traffic had been taken; it was, however, believed to vary from 300 or 400 to 3,000 vehicles, the latter number being reached on pleasant days. Possibly the difference in climate between the two countries was so great that the above-described roads would not stand better than those now made in London; but the economy in first cost, and other advantages of macadam roads, might induce some engineer to give the American method a trial.

Mr. J. Price referred, through the Secretary, to a kind of paving which he had used to a small extent. It possessed the merit of cheapness; and he believed would be suitable for heavy traffic; though he had never had an opportunity of trying it under such circumstances. It consisted of a thick bed of Portland cement concrete, containing a large quantity of fine-broken stone; and while in a soft state it was paved on the top with angular pieces of granite, or other hard stone, set with the flattest face upwards, fitted into each other at random. This he called "breccia pavement," from the geological term for angular conglomerate. It possessed the bearing strength of concrete with the hard surface of stone. The cement occupied the irregular interstices between the stones, and formed a solid mass adhering to the stones, no one of which could sink lower than the others. Irregular rubble stones could be used, thus avoiding the great cost of square sets. The joints not being in straight lines, ruts could hardly form. The labour of setting was not so great as might be expected. Small sections of concrete were boarded off—just what could be covered with the stones before the cement began to set. The pavior worked sitting, and was provided with a light hammer to knock off weak points from the stones; he fitted in crevices with angular spawls. This breccia pavement was of course perfectly watertight.

Mr. David C. Proudfoot observed, through the Secretary, that he found ordinary macadam roads unsuitable for town carriageways,

and in Edinburgh these would soon have disappeared from the centre of the city. In the construction of carriageways for heavy traffic, whether paved with stone or wood, it was absolutely necessary to have a strong concrete bed or foundation, from 6 to 9 inches thick. For durability and economy there was no mode of constructing a city carriageway for heavy traffic which could excel the following:—1. Foundation of Portland cement concrete, 9 inches thick. 2. Granite sets, 3 inches thick by 7 inches deep, built into a bed of fine concrete, about 2 inches thick, laid over the concrete foundation. 3. The whole of the paving joints grouted with Portland cement grout. The cost of this work in Edinburgh would be about £1 per superficial yard, and the road would require no repair for at least ten years. The noise caused by traffic passing over a carriageway so constructed was not distressing, the close grouting of the joints tending greatly to lessen it. The surface was easily cleaned, and, as a sound and substantial carriageway for bearing heavy city traffic, it could not be excelled. Carriageways when formed with wood should have, as already stated, a strong concrete foundation, finished and floated smooth on the surface for the wood blocks to rest on. All the timber should be carefully selected, and of the first quality of Wyborg or St. Petersburg red deals. The blocks should be laid about $\frac{3}{8}$ inch apart between the courses, and the joints filled to the surface with boiling asphalt, composed of pitch, ground chalk, and heavy creosote oil, without using any other mixture. The work and material should be closely superintended, with the view of having the work finished in a sound and substantial way, as there was a great tendency nowadays to hurry over and scamp the work. The blocks used for wood paving should be from 5 to 6 inches deep, with the view of reducing the first cost, as they would require renewal (under the same conditions of traffic, and atmospheric influence) oftener than granite.

Mr. Hugh Shearer remarked, through the Secretary, that all the speakers seemed practically agreed with Mr. Deacon, that the first essential of a good street was a solid, uniform foundation. The further desiderata were, a smooth surface, with as little noise as possible; the material should be easy to keep clean; it must not be slippery; and it should be durable without being costly. Asphalt, wood, and granite sets were the only rival materials which seemed available. Asphalt was smooth, clean, and comparatively noiseless, but was fatally slippery, and was therefore practically out of competition as a material for street paving. Wood was smooth, at least for a time, and was comparatively noiseless, and on the whole it gave a good foothold; but it was liable to absorb the foul liquids which

accumulated in streets, and so could not be kept clean and healthy. It was, moreover, costly, requiring frequent repairs and renewal, and could not, therefore be used on any large scale as a paving material on the busy thoroughfares of great cities. Granite sets, laid in the manner described in Mr. Deacon's Paper, viz., on a solid uniform concrete foundation, and fixed in place by a grouting of asphalt and gravel—granite chips being preferable—would be admitted to give a surface incomparably more durable and less costly than either of the other materials named. It could be easily kept clean; and when evenly laid, traction upon it was easier than on wood; and, excepting in cases where very dense kinds of granite were used, it had been proved to give as good a foothold as wood. Granite sets, however, as at present treated, made, it could not be denied, very noisy streets. But this was not a necessity; for if the street traffic were watched it would be observed, that the grinding or rattling noise produced by the advancing wheels on the macadam, or on the ordinary sets, instantly ceased when the vehicles reached the granite crossing, which they rolled silently over. The reason of this was, that the granite crossings were axed on the top to an even surface. The noise on granite paving arose from the constant concussion caused by the rough, uneven surface with which the sets were usually made, and the wide joints with which they were usually laid; therefore, where quiet streets were wanted the sets must be axed on the top to an even surface, and laid with joints of not more than ½ an inch. Then there would be little more noise on granite sets than the click of the horses' feet, such as was heard on asphalt. If the granite used was not too close in the grain, dressing on the top would in no degree render the sets slippery. Unquestionably sets so dressed and laid would endure much longer, and therefore might be reduced in depth, and a saving effected thereby, equal, at least, to the extra cost of dressing. It thus appeared that granite sets possessed in a more or less degree all the requirements for the wearing surfaces of great thoroughfares, viz., smoothness, little noise and minimum wear and tear on vehicles and stones, cleanliness, imperviousness to wet, safe foothold, durability, and moderate cost.

Mr. E. L. STEPHENS remarked, through the Secretary, that he had always found the best figure for granite or other hard-stone paving sets for heavy traffic to be 4 inches wide, 6 inches deep, and 8 inches long, laid with ¾-inch joints. In streets of lighter traffic, sets 3 inches wide, but of the same depth and length were perhaps better.

Mr. R. VAWSER stated, through the Secretary, that his experience as surveyor to the Corporation of Warrington enabled him to confirm Mr. Deacon's conclusions to a very large extent.

In 1868 and each succeeding year he had laid down set pavements much in the style advocated. As a rule he found a set 4 or 5 inches deep sufficient on a level street, when laid on a firm unyielding foundation; whereas without such foundation any pavement was rapidly ruined. It had not been the practice in Manchester to pave on specially prepared foundations, and it was lately announced that last winter's frost had caused damage to the paved streets exceeding £12,000. Some of the principal paved thoroughfares in Manchester had now been repaired temporarily with broken stones, to render them safe until the paviors had time to attend to them. This could not have happened had the sets been paved on a proper foundation. When grouting with asphalt, the sets and stones to fill up the interstices should be quite dry, or the asphalt would sometimes cool, and not run down into the joint nor adhere firmly to the stones. Instead of concrete he generally found it convenient to construct foundations of stones carefully laid by hand, described in the Paper as the old practice in Liverpool. This was chiefly on account of the gas and water pipes, which had frequently to be relaid at a lower level, involving new service pipes and other alterations and repairs. The gas and water companies could seldom be induced to commence their work until the corporation had made some progress, and very often the foundation was cut up from end to end for new gas or water pipes, as soon as it was laid. With a rubble foundation time could be allowed for the ground to consolidate, an advantage which concrete did not seem to possess. Where gas and waterworks were under the control of the corporation the objection had less force. There could hardly, he thought, be two opinions about the advantage of a first-class foundation wherever it had been tried. The life of the paved surface was greatly increased, and the cost of scavenging and repairs was materially reduced. The cost of the foundation was very little compared with the surface, and when well done would practically last for ever, for it would not need renewal when the surface was worn down. A good foundation enabled a much less depth of granite set to be used, an item of expense that would go a long way towards the cost of the foundation. As regarded size and quality of set, much depended on local considerations; but he thought the sizes named by Mr. Deacon were well chosen, and that the complaint of slippery stones so often heard of was due more to the gradients of the surface, both transversely and longitudinally, and to the size of the sets and their distance apart, than to the hardness of the stone which formed the surface.

May 6, 1879.

JOHN FREDERIC BATEMAN, F.R.SS.L.&E., President, in the Chair.

THE following Candidates were balloted for and duly elected:—JOSEPH LEECE, as a Member; WILLIAM BEATTIE, JOSEPH SAMUEL BEEMAN, Stud. Inst. C.E., WILLIAM SANTO CRIMP, Stud. Inst. C.E., CLEMENT DUNSCOMBE, M.A., JAMES STAATS FORBES, Jun., Stud. Inst. C.E., DEAN GAUNTLETT, WILLIAM BERNARD GODFREY, Stud. Inst. C.E., HARRY HAWGOOD, JOHN ELLIS HUGHES, THEODORE BENT HUTTON, HENRY ALEXANDER JAMES, FREDERICK WILLIAM JOHNSON, Stud. Inst. C.E., HENRY BATSON JOYNER, JAMES THOMAS KOUGH, WILLIAM CUTHBERT LEWIS, Stud. Inst. C.E., FREDERICK JAMES MCLAUGHLIN, JOSEPH NEWEY, JOHN POLLARD, Stud. Inst. C.E., GEORGE BERNARD REYNOLDS, Stud. Inst. C.E., ALEXANDER THUEY, and CHARLES WOOD, as Associate Members; JOHN WILLIAM DEVEREUX BAIN, EDWARD CARPMAEL, B.A., WILLIAM THOMAS MOUSLEY, and JAMES HALIFAX WESTERN, *Capt.* R.E., as Associates.

It was announced that the Council, acting under the provisions of the Bye-Laws, had transferred EDWARD BAZALGETTE, HENRY IRWIN, CHARLES JAMES MORE, JOHN SALTER, and JAMES PAGE SYMES, from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted as Students of the Institution:—HORACE ALLEN, ROBERT ANDERSON, JOHN BOOTH, FREDERICK GEORGE COOKE, HENRY COWE, ALFRED THOMAS DAVIS, GEORGE HILL DAY, ALEXANDER LOW DICKIE, JOSEPH ALOYSIUS DOOLAN, ARTHUR HENRY GLENDINNING, MATHEW BUCHAN JAMIESON, JAMES IBBS LAWSON, NORMAN FREDERIC MCLEOD, MICHAEL NETHERSOLE, JOSIAH PIERCE, Jun., DAVID CAMPBELL RATTRAY, HAROLD SEBASTIAN VOGAN, WILLIAM ORME WEDLAKE, THOMAS DUNCAN WEIR, and DOUGLAS FITZGERALD WORGER.

The discussion upon the Papers by Mr. DEACON and Mr. HOWARTH, on "Street Carriageway Pavements," and "Wood as a Paving Material under Heavy Traffic," respectively, occupied the whole evening.

May 13, 1879.

WILLIAM HENRY BARLOW, F.R.S., Vice-President, in the Chair.

JOINT BUILDING FOR APPLIED SCIENCE SOCIETIES.

MR. BARLOW read to the meeting the following communication, which had recently been made to the Iron and Steel Institute by Dr. Siemens, Past President of that Institution, and stated that the Council was about to take the matter into consideration:

"It having been recognised by the Members of the Iron and Steel Institute, as well as of other Institutions, that it would be desirable to have a building of sufficient capacity to represent the Societies cultivating various branches of Applied Science, as suggested in my Inaugural Address to the Iron and Steel Institute, in 1877, I move that the Committee then appointed to promote that object, and to confer with other Societies, be re-appointed; and with the view of giving effect to their efforts, I hereby offer to give the sum of £10,000 in aid of the construction of such a building, on a suitable site at Westminster; the work to be carried into effect under the supervision of a Joint Committee, to be presided over by the President of the Institution of Civil Engineers, or his representative."

The discussion upon the Papers by Mr. DEACON and Mr. HOWARTH on "Street Carriageway Pavements," and "Wood as a Paving Material under Heavy Traffic," respectively, occupied the whole evening.

May 20, 1879.

JOHN FREDERIC BATEMAN, F.R.SS.L.&E., President, in the Chair.

No. 1,612. "The Improvement of the Bar of Dublin Harbour by Artificial Scour."[1] By JOHN PURSER GRIFFITH, Assoc. M. Inst. C.E.

THE history of Dublin as a port may be said to date from the year 1707, when, by an Act of the Irish Parliament, the conservancy of the port was vested in the Corporation of the City of Dublin. This Act empowered them to erect a Ballast Office and to levy tonnage dues, and the funds so collected were to be expended in amending and cleansing the river channel, which had become extremely shallow. The difficulties to be overcome before Dublin could be made a safe and commodious port will be better understood if the physical features of the vicinity are briefly explained. The city is situated close to the mouths of the rivers Liffey and Dodder, at the head of a bay 6 miles deep and 5½ miles wide. Large quantities of sand brought in by the sea have accumulated in the bay, forming extensive strands, which are laid dry at low water for a distance of about 2½ miles seaward. At the date above referred to, the combined waters of the Liffey and the Dodder flowed across the sands at low water, dividing them into two sections, known as the North and South Bulls. The channel thus formed was subject to constant alterations in depth and direction from its exposed position; and this being the only channel by which vessels could reach the city, the early attempts to improve the harbour naturally took the direction of providing a permanent and deep approach to the port.

The first improvement undertaken was the formation of a straight channel from the city to Ringsend in 1711. It was bounded on the north side by a bank of timber work and stones, while on the south side a masonry quay wall was begun. These boundaries of the channel occupied pretty closely the lines of the present north and south quays. While they were in progress a still more important work was undertaken—the construction

[1] The discussion upon this Paper occupied portions of two evenings.

of a jetty of frames and piles extending from Ringsend to the site of the present Pigeon House Fort, a distance of 7,938 feet, and thence for a length of 9,816 feet to the eastern spit of the South Bull. The objects which the designers of this work had in view were, to direct the river in a straight channel to the sea, to shelter the channel in south-easterly gales, and to prevent the encroachment of sand from the South Bull. The regular dredging of the channel was also begun, with the twofold object of supplying ballast for the shipping and of improving the navigation. The timber jetty made but slow progress, for in 1729 the Corporation appear to have sought powers to raise £3,000 for the completion of the piling. In 1730 an old hulk was sunk, to protect the eastern end of the frames; and in 1735 a floating-light vessel was moored there. The maintenance of this timber work was soon found to be very expensive, and even when efficiently maintained it formed but an imperfect shelter to the channel. Accordingly, about 1748, the first length, from Ringsend to the Pigeon House, was replaced by a double line of rubble retaining walls, with sand filling between. In 1761 the work of replacing the second length to the eastward of the Pigeon House was begun. The first operation was the construction of the present Poolbeg lighthouse, at the extreme east end of the pier, or Great South Wall as it is now called.

The unusual course of beginning a work of the kind at its extreme and most exposed point was adopted, with the view of as soon as possible replacing the floating light, which was frequently displaced in stormy weather, by a permanent and efficient lighthouse, and of affording protection to the new wall while in course of construction.

Taking into consideration the date at which it was undertaken and the appliances then available, this work must be acknowledged as a remarkable feat of marine engineering. After the completion of the lighthouse the wall made but slow progress, and the sand from the South Bull began again to fill up the navigable channel, through breaches in the piling where the timber had decayed. This delay in effecting any material improvement to the harbour caused general dissatisfaction, and led the Irish Parliament, in the year 1786, to transfer the conservancy of the port from the City Corporation to a special board, called the Corporation for Preserving and Improving the Port of Dublin, but more familiarly known as the Ballast Board. Under their direction the Great South Wall was finished in 1796, and a small harbour or basin was made at the Pigeon House, to shelter vessels in easterly winds.

A comparison of the soundings taken by order of the Corporation in 1711, by Captains Burgh and Perry in 1725, and by Captain Bligh in 1800, indicates that the completion of this work, at an expenditure of about £200,000, had attained, in a great measure, the objects for which it was designed, inasmuch as the channel from Poolbeg to the city was more sheltered, and also somewhat straighter and deeper, than before the construction of the pier. It has been alleged that the Great South Wall was only partially successful, as it did not produce increased depth of water to seaward on what is known as Dublin bar; it is, however, but just to those who designed it to state that no such object was aimed at. Previous to the construction of the wall, the bar formed no material obstacle to vessels frequenting the port, seeing that, with one or two exceptions, there was shallower water in the channel up to the city than on the bar. As soon, however, as the wall was finished, the sweep of the tide round the lighthouse produced much deeper water in the neighbourhood of Poolbeg than farther out to sea. This naturally drew attention to the bar, and gave rise to the belief in some minds that a bar was forming across the entrance, while in reality no reduction in depth had taken place. The Author's wish, in thus alluding to the bar, is to remove any impression that its formation is due to deposit brought down by the rivers. Dublin bar is simply a submerged beach, forming the connecting link between the North and South Bulls.

About the year 1800, the Ballast Board appear to have applied to the Directors General of Inland Navigation for funds to proceed with farther improvements to the port, the chief of which was a wall or embankment running out from the Clontarf shore towards Poolbeg lighthouse. The Directors General, feeling the want of reliable information respecting the state of the harbour, instructed Captain Bligh to make a survey of the bay, showing the depth of water in the river and upon the bar, and giving all necessary information respecting the tides and currents. He was also to report what he considered to be necessary for the improvement of the port. Evidently the Government felt the importance of the subject, for during the years 1800, 1801, and 1802, they consulted Sir Thomas Hyde Page, a Royal Engineer, Captain Corneille, and Mr. Rennie, in reference to the improvement of Dublin harbour. Captain Bligh's survey, on a scale of 4 inches to 1 Irish mile, is the first survey of any value of the river and bar. The accuracy of his soundings about the bar is attested by Mr. Rennie, who checked them for his own information shortly after the survey was made. From this survey it was found that

the bar extended in the form of a hook across the entrance to the river, the deepest, or south channel, being between the light-house and the point of the hook, where there was 8 feet in depth at low water of spring tides, while in a direct line seaward across the bar there was only a depth of 5 feet.[1] Captain Bligh, in his report, states that the depth of water in the south channel of the bar was greater than in almost any other part of the harbour; that in fact, as regards navigation, no bar existed. He therefore turned his attention to the improvement of the channel up to the city, and recommended that a wall should be built along the north side of the channel, from the east end of the north wall quay as far as Poolbeg (Plate 1, Fig. 1). The width between the north and south walls at Ringsend was to be 700 feet, increasing to 2,000 feet at the lighthouse. By the construction of this northern wall he aimed at confining the waters of the Liffey and Dodder to their legitimate channel at all states of the tide; and, by not allowing them to spread over the northern or Clontarf strand, he hoped to gain the full advantage of the upland waters in keeping the navigable channel free from deposit, while in addition the sand brought down by the Tolka from the northern strand could no longer be carried into the channel. By confining the flood tide to the channel, and preventing its dispersion over the north strand, Captain Bligh expected an increase in its velocity, and the introduction of a corresponding additional volume of tidal water up to the quays. He laid great emphasis on the prevention of anything like an obstruction to the free ebb and flow of the tide, and with this view recommended that no steps or slips should be allowed to project beyond the face of the proposed wall. He attributed many of the defects in the old channel to the irregular line of the Great South Wall; and found fault specially with the projection of the Pigeon House basin into the channel. This he proposed to remedy by continuing the north wall of the basin westward. Although Captain Bligh expected that the construction of the northern wall would greatly increase the efficiency of the river and tidal waters in keeping the channel free from deposit, yet he acknowledged that it would have but little effect in deepening the channel by removing existing deposit. To complete this necessary improvement he recommended the immediate employment of three hundred and fifty men and fifty barges to dredge the channel systematically,

[1] Captain Bligh's datum is not accurately defined; it was probably an extreme low water like the Ordnance datum for Ireland, which is 1·43 foot below Mr. Giles's datum.

and under careful supervision, and that this should in any case be begun, whether the construction of the wall was undertaken or not.

The Tidal Harbour Commission, referring to this scheme in their report of the year 1846, say, "Had Bligh's suggestions in 1801 been acted upon at once, Dublin harbour would probably have been in a better state a quarter of a century ago than it is now."

The Directors General of Inland Navigation, in a report to the Lord Lieutenant of Ireland, dated the 27th of August, 1800, appear to have recommended the construction of this second or north wall. Sir Thomas Hyde Page, commanding the Royal Engineers in Dublin, to whom the subject was referred, approved of the proposal on the ground that "it possibly might, by confining the flood and the ebb tides to a certain channel, cause deeper water between the bar and Dublin, and also through the south and east channels" of the bar. He observed, however, that great caution would be required not to extend this wall too far into the bay, lest the sand should accumulate on its south face, in the same manner as it had already done on the south side of the Great South Wall, and thus form a far more serious bar across the river entrance than existed at the date of his report.

In addition to this wall, he recommended that part of the bar should be raised with old hulks, fascines, and stones above high-water level to form an island (Fig. 1). This work was to extend from the east buoy for a length of ½ mile towards the west end of the bar. The advantages claimed for the island were, that it would afford shelter to the harbour entrance and Poolbeg in easterly winds, and tend to produce increased depth of water in the bar channel. His estimate for the northern wall was £168,000, and for the works on the bar, including a lighthouse, £78,000, making a total of £246,000. Towards the close of 1801 the Ballast Board, at the request of the Directors General of Inland Navigation, forwarded a statement in support of their scheme for the formation of a northern wall or embankment running out from the Clontarf shore to the North Spit buoy, nearly opposite Poolbeg lighthouse. They stated that they looked for the preservation and improvement of the harbour to the admission of the largest possible quantity of tidal water, and to the reflux of this water properly directed; feeling convinced that the upland waters discharged by the Liffey and the Dodder would not of themselves suffice, even under the most favourable circumstances, to effect this object. In support of this latter con-

clusion, they drew attention to the fact that the Liffey was unable to cleanse the narrow channel through the city between the north and south quays, and that most of the city sewage was deposited in the channel above Ringsend. By the construction of the northern wall the north side of the harbour would receive similar advantages to those conferred on the south side by the completion of the Great South Wall, namely, shelter from easterly winds, and the stoppage of the encroachment of sand from the North Bull; while the formation of a deeper channel across the bar would probably result from the ebb being directed through the contracted entrance at Poolbeg, instead of expending its energy over the North Bull.

The Ballast Board claimed for their proposed wall the merit that it did not run counter to nature beyond what was absolutely necessary. They stated that their aim was to assist nature as far as practicable where its efforts appeared to be usefully directed, and that they expected, on the completion of the northern wall, the two great piers of the harbour would afford mutual protection, and that their joint action in improving the bar channel would be much greater than could result from either singly.

It was at this juncture that the Directors General sought the advice of Mr. Rennie, whose experience in harbour works was probably unequalled at the time. After reviewing what had already been done towards improving the harbour, and what had been recommended by his predecessors in furtherance of this object, he proceeds to say that, "from the little good that has been produced by the extensive works already executed in improving the depth of water on the bar at Dublin harbour, I cannot say I have any very sanguine hopes of much good being produced by any works which can be added at a moderate expense. The scouring away of bars is but an uncertain operation at the best, and can only be done by bringing additional water to act on them, or by confining the action of what water there is to a narrower channel."

His recommendations were the following (Fig. 2):

1st. "To build a pier from near the Spit buoy of the North Bull to the Clontarf shore, about ½ mile east of the sheds, leaving an opening of about 550 yards between its head and the south pier.

2nd. "To embank the South Bull, so as to enclose about 1,300 English acres, statute measure, and to make a large opening in the south wall, near the Ringsend, to admit the tide into this space or reservoir.

3rd. "To make low jetties on the flat shore from the channel towards the Clontarf shore, to direct the water as well on the south as on the north side of the ship channel in one course, and both in the first quarter of flood and last quarter of the ebb, when its scouring power is the greatest."

The capacity of the northern and southern reservoirs combined was estimated by him at 36,000,000 tons of water at spring tides, and by the formation of the northern pier this large body of water would ebb and flow through the contracted entrance at Poolbeg. Great, however, as the quantity of water might appear, his opinion was that, even with the assistance of dredging on the bar, no greater permanent increase than 1 foot in depth of water could be expected. This, it must be confessed, would have been a small result for an estimated expenditure of £252,384.

Mr. Rennie's idea appears to have been that if any greater depth was to be looked for on the bar, both the northern and southern piers would have to be extended eastward. An increased depth of 3 feet might, he thought, be attained, if the northern pier was extended 1,100 yards and the southern pier 800 yards, the dredging of the bar being proceeded with at the same time and for some time after the completion of the piers. His estimate for these extensions, and the works connected with them, was £403,488, bringing up the amount to be expended upon the improvements which he proposed to the sum of £655,872.

As this increased depth would only give from 8 to 9 feet depth on the bar at low water of spring tides, Mr. Rennie turned his attention to devising a scheme which might give promise of greater success. He clearly saw the necessity of providing a permanent deep-water entrance to the port, and such a result, he believed, might be attained by the construction of a ship canal from the city to some point on the adjacent coast. This plan had already been proposed by Captain Perry at the early part of the last century. His proposition was to construct a canal along the north shore of the bay to Sutton, or through the isthmus of Howth to the present site of Howth harbour. The scheme met with great opposition from the port authorities at the time, and was ultimately abandoned. Mr. Rennie suggested three sites for the deep water entrance—Sutton on the north side of the bay, and on the south side Sandycove, and Dunleary, the present site of Kingstown harbour. He gave preference to the latter, and in this opinion was supported by Captain Huddart, to whom he referred the question

from a nautical point of view. His estimate for the construction of this ship canal and a harbour at its entrance was £489,734.

It is not very clear, from Mr. Rennie's report, whether his intention was that the canal entrance should entirely supersede that by the bar, or whether it should only be used by vessels of large draught. If the former, then there can be but little doubt that Dublin, as a port, would have been greatly injured had his proposal been carried out.

The necessity for all sailing vessels engaged in the coasting trade, having to be towed through a long and circuitous canal from Kingstown to the city, would virtually have been prohibitive to the great extension which has of late years taken place in this particular branch of the trade of the port. Another point should not be forgotten, that almost all the costly works already constructed with a view of improving the river entrance must have been abandoned, and the large sums of money expended considered as so much money wasted. If, on the other hand, the canal was only to be considered as an adjunct to the river entrance, to be devoted merely to large vessels, then it appears more than probable that the cost of maintaining the double entrance would have been too great a financial burden on the revenue of the port. Captain Bligh seems to have been of this opinion, for he wrote: "I impress it strongly as a principle, that a canal and the Liffey would destroy each other, as both would be too burthensome to keep up, and that the general bias would at last go in favour of the latter."

The Directors General of Inland Navigation, in reporting to Government upon the various schemes proposed, concluded by expressing their opinion as follows: "Considering, therefore, the objections, the expense, and the difficulties which may occur in the execution of all, except the pier from the north side of the harbour, we desire to defer them until we shall see which of them be matter of indispensable necessity." [1] It will thus be seen that their views were almost equivalent to a direct support of the Ballast Board's proposal, to which reference has already been made.

From the year 1802 to 1819 there is but little reference to the proposed northern wall. It is probable that, in the face of Mr. Rennie's report and the great divergence of opinion among the other engineers and naval officers consulted relative to the improvement of the port, the Government were unwilling to make any grant to the Ballast Board. During these years the Board seem to have used their surplus revenue in efforts to improve the

[1] *Vide* Report, July 10, 1806, p. 94.

channel along the Great South Wall, and in replacing the old rubble quay walls by new walls faced with granite ashlar.

The sand excavated in the channel, and not required for ballast, was chiefly used in backing up these walls. Steam dredging was introduced in 1814, the dredger having a bucket-ladder projecting beyond the side of the vessel, while the crab-winches for altering the position of the vessel while dredging were worked by hand.

In 1814 the Government paid the Ballast Board £100,183 for the site of the Pigeon House Fort, including the adjoining basin, which was required for military purposes. Having discharged a portion of their debenture debt with these funds, the Ballast Board found themselves possessed of a large sum of money, which they determined to use in the execution of their favourite project—the construction of the Great North Wall.

Before commencing active operations in connection with this work, the Board decided on having an accurate survey prepared, showing the existing state of the harbour and bar. This was entrusted to Mr. Francis Giles. It was made with extreme care and in great detail, and forms a most valuable record in connection with the history of the port, affording a ready means of comparison with surveys of a subsequent date. Mr. Giles's datum[1] now forms the standard low water of the port, and to it the soundings given on recent Admiralty surveys of the bay have been reduced.

From Mr. Giles's survey (Figs 3 and 9) it appears that at low water of spring tides there was a depth of 6½ feet of water on the bar in the direct or east channel, of 12 to 15 feet in the Poolbeg anchorage immediately inside the lighthouse, and at the deepest part of the Ford Bank east of the Pigeon House of only 7 feet, while west of the Pigeon House up to the quays there was but a depth of from 2 to 4 feet. On the completion of his survey and observations of the currents in the bay, Mr. Giles was probably in a better position than any of his predecessors to form an opinion on the question of improving the harbour. In reporting on this subject, in compliance with instructions from the Ballast Board, he cordially supported the proposal to construct the northern embankment or wall from the Clontarf shore towards

[1] This datum was the mean low-water mark of spring tides observed as follows: At Dunleary old harbour, from November 1815, to March 1816; at Howth harbour, from May 1817, to November 1818; at Dublin lighthouse, from June to November 1818. The mean range of the same spring tides was 13 feet. The mean low water of neap tides was 3 feet 6 inches above datum, with a range of 6 feet 6 inches.

e North Spit buoy; but he recommended that an opening ould be left at the shore end 600 feet wide, to allow of a free ssage for the tidal waters north of the Green or Bull Island, the sand island on the North Bull was called. This opening d been proposed by Captain Corneille in 1802; but at that ne the Directors General of Inland Navigation feared that the od tide flowing through this opening would carry sand from e North Bull into the harbour, and that the injury thus done to e port might more than counterbalance any advantage to be ined by the opening.

Mr. Giles, however, supported his recommendation on the llowing grounds:

1st. That the Green or Bull Island had accumulated to such an tent since the above objections were made, that it would act as complete barrier between the North Bull sands and the channel the north of the island, and prevent any risk of these sands ing carried into the harbour through the proposed opening.

2nd. That the tidal waters flowed into the north channel from e west or Clontarf end as well as from the east or Sutton end, id ebbed in like manner; and that as a consequence the proposed ening would still allow a large volume of water to ebb and w to the westward, thus adding materially to the tidal capacity the harbour.

3rd. That the opening would be advantageous for the carriage materials in lighters from Sutton during the construction of the all. And

4th. That in any case it would be prudent to maintain the open- ig till it should be finally determined whether additional tidal ater would be required for scouring the bar, or till the opening as proved to be injurious to the interests of the port. Should ldditional tidal water be required at any time, Mr. Giles proposed close the east end of the channel with an embankment from utton to the island, thus forming it into an additional reservoir, ith a capacity of about 7,000,000 tons of water between high and w water of spring tides, which would necessarily pass through ie harbour, and ebb and flow across the bar (Fig. 6).

In regard to the width of the entrance to the harbour at Poolbeg, recommended that it should be left an open question until the ork had made some progress, and the effects likely to be pro- iced became better known. His orignal intention seems to have en to raise the wall throughout to 6 feet above high water of ring tides, and to make the entrance from 500 to 700 yards ide.

In 1819 the direction of the Great North Wall was jointly decided on by Mr. Giles and Mr. Halpin, the engineer of the Ballast Board. Starting from the western end of the Bull Island, the embankment was to extend to the North Spit buoy in a direction S.E. ¼ E. Besides fulfilling the conditions of sheltering the harbour, preventing the sands of the North Bull encroaching, and admitting as great a volume of tidal water as practicable, they believed the direction chosen for the embankment would be advantageous in reducing the risk of damage to the work from south-easterly gales.

The wall was begun in 1820, and was carried out with great vigour, every effort being made to expedite its progress. It was principally formed of rubble stone brought from the limestone quarries on the north side, and the Dalkey granite quarries on the south side of the bay; and the opening between the island and the shore was crossed by a wooden bridge.

The effect of the new wall soon became apparent in the increased velocity of the current past Poolbeg lighthouse, and alterations in the neighbouring sand banks. These results were so marked that they caused some uneasiness, and the Ballast Board in the autumn of 1822 requested Mr. Telford to report upon the state of the work and on the effects already produced. From his report it appears that a length of 5,500 feet of the embankment was finished to 6 feet above high-water level of spring tides, 1,500 feet to the level of high water of neap tides, and about 500 feet to half-tide level. He found that the sand banks inside the wall had been considerably lowered, while that part of the bar immediately opposite the entrance had been lowered 2 feet, so that a new and direct channel had been already formed across the bar from 8 to 9 feet deep at low water of spring tides. Mr. Telford considered the width of the entrance still too great, and supported Mr. Halpin in the opinion that the embankment should be extended, but that the extension should not be raised above half-tide level until its effects were fully understood. Mr. John Whidbey was consulted in the same year. He, too, appreciated the value of the work already done; but recommended that any further extension of the wall should be postponed till more experience was obtained of the changes produced by the new works as they then stood. The Ballast Board, however, adopted Mr. Telford's view, and the extension was carried out as he suggested.

The Great North Wall was completed in 1825, having cost £103,055 Irish currency, or about £95,000 British. The total length of the wall exceeds 9,000 feet, and it remains at present virtually in the

same condition as when finished, except that towards its extremity it has been somewhat lowered by storms and the undermining action of the scour (Figs. 6 and 7). The varying level of the wall forms a remarkable feature in its design; and, although presenting the appearance of an unfinished work, will, the Author believes, upon consideration, show how much care and forethought were bestowed upon this work by those under whose direction it was carried out. Fully to appreciate its value, it is necessary to have a general knowledge of the currents in the bay; and for this purpose the most important fact to be borne in mind is, that on the north side of the bay, during the first half of the ebb, the tide runs westwards towards the bar, and thence southwards in the direction of Kingstown, while, during the last half of the ebb and the whole of the flood, the tide sets eastwards past the Bailey. During the first half of the ebb, the tidal and river waters within the Great North and South Walls pass partly over the submerged portion of the northern embankment, and partly through the harbour entrance between its termination and Poolbeg lighthouse. The current out of the harbour during this time is comparatively slack, and in no way interferes with the navigation of vessels in and out of the port. It is also probable that it produces little or no effect in deepening the bar channel, but only joins the bay current, and sets south towards Kingstown. As soon, however, as the lower portion of the northern wall is uncovered, the remainder of the tidal and river waters within the harbour must pass through the contracted entrance at Poolbeg, which is only 1,000 feet wide. The result is a great increase in the velocity of the current, which somewhat exceeds 3 miles per hour during spring tides, and a marked impression on the bar by the removal of sand. This sand-bearing stream joins the bay current, which by this time is setting eastwards, and ultimately deposits on the North Bull a portion of the sand removed from the bar, while the rest is carried into deep water.

The tidal water entering on the flood comes from the south, bringing back some of that discharged on the first half of the previous ebb. It appears, however, that except at neap tides, but little of the water discharged during the second half of the ebb returns, in consequence of the current at the north side of the bay still setting east, and that the harbour is thus saved from injury by the return of sand upon the flood tide.[1]

[1] Neap tides with a small rise and fall form an exception, for frequently in such cases the lower portion of the Great North Wall does not uncover till close

Had the Great North Wall been raised above high-water level for its entire length, there would have been a strong current through the entrance during the whole of the ebb. In that case the current on the first half of the ebb would become a sand-bearing stream, and on meeting the opposing bay current would either deposit sand and form another shoal more difficult to deal with than the bar, or be deflected to the southward, and re-enter the harbour on the flood, bringing back whatever sand was still held in suspension.

Although Mr. Halpin, in his evidence before the Municipal Corporations (Ireland) Commission of 1835, candidly stated that the operation of the new wall was different from what he had anticipated, inasmuch as he expected an increase of depth in the south channel, and not the formation of a new and direct channel, yet it appears probable that both he and Mr. Giles understood the value of the nine hours eastward set of the tide at the north side of the bay, and purposely did not raise the Great North Wall above its present level as a precaution against the formation of shoals, or the return of sand into the harbour. They also had in view the great advantages afforded to navigation by the slackness of the current at the last half of the flood tide and first half of the ebb, when there is the greatest depth of water on the bar, and the largest number of vessels enter and leave the harbour. A strong current at this time would obviously be extremely dangerous, and detrimental to the interests of the port. By the year 1833, the depth of water on the bar had increased to 10 feet at low water of spring tides; and considerable improvements had been made in the channel from Poolbeg to the quays by dredging; yet in the face of all that had been done, the old scheme of a ship canal to Kingstown was revived. The reasons now brought forward in its support were, first, the formation of a

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to the time of low water. The result is that the velocity of the current is very small, and that a large proportion of the water discharged returns with the flood tide. From the following considerations it would seem that these tides produce no scouring effect on the bar, and consequently that no injury results to the harbour from the return of any of the water discharged. The range of a neap tide frequently does not exceed 5 feet, and the maximum velocity of the current through the entrance, on the ebb of such a tide, seldom reaches 1 mile per hour. Prior to the construction of the Great North Wall, Mr. Giles observed that during spring tides the velocity of the main set of the ebb across the bar was 1¼ mile per hour, and during neaps nearly 1 mile per hour. As this velocity did not produce any scour on the bar in 1819, it appears a reasonable conclusion that no greater effect is produced at the present day, by currents of equal velocity where the volume discharged has not materially altered.

sand bank called the "Mumbles" inside the harbour, and close to Poolbeg lighthouse (Fig. 6), the result, as alleged, of the construction of the Great North Wall; and secondly, the state of the channel up to the quays, which the promoters of the canal scheme maintained had been made unsafe for vessels to ground in by the recent dredging operations. The whole subject was referred to a Select Committee of the House of Commons, who appear to have been favourably impressed by the proposal of a ship canal; but it was successfully opposed by the Ballast Board. The agitation, however, induced the harbour authorities to make greater exertions to improve the channel.

The complaint respecting the "Mumbles" was no doubt founded on fact, as this bank accumulates at the present day, and has to be dredged away at intervals of a few years. It is composed of coarse sand and broken shells, and its formation has been the subject of much controversy. The Author is inclined to attribute it to the groyne-like action of the Great South Wall, which runs out obliquely to the axis of the main stream passing through the harbour entrance. This stream, on the last half of the ebb, carries large quantities of sand out of the harbour, as evidenced by the wasting away of the North Spit. It is flanked on its southern margin by weaker currents and slack water, resulting from the projection of the Great South Wall, conditions which favour the formation of eddies and the deposit of coarse materials along this line. The position of the Mumbles agrees closely with this boundary of the outflowing stream, while materials similar to those of which the bank is composed are to be found not far distant. This deposit, although objectionable in many ways, affords a valuable supply of coarse sand for use in the port works; and, whenever the bank is dredged away, the sand is stored with this in view.

In 1835 Sir William Cubitt reported upon the state of the harbour. Referring to the improvement of the bar, he says: "The great increase of depth and improved channel over the bar I attribute entirely to the erection of the Great North Wall, a measure founded upon sound principles, and carried into effect in a manner well calculated to effect the desired purposes—viz., that of checking the influx of sand upon the flood tide from the North Bull into the harbour, and giving an increased impetus at the ebb tide by means of narrowing the stream, and confining it to a direction suitable for keeping open the best channel, the effect of which is already shown by an increased depth of 5 feet over the east bar since the erection of the Great North Wall."

Captain Washington, in his report written in 1845, on the

harbour of Dublin, as one of the Tidal Harbours Commissioners, referred to the Great North Wall as follows:

"The propriety of this measure, which involved so heavy an expenditure, has been a subject much controverted amongst persons connected with the port; but it is believed that there is now but one opinion as to its beneficial effects, and that the plan evinced both good judgment and skill."

Mr. James Walker, writing in 1861, expresses his opinion on the subject in these words: "I beg" . . . . "to say that the success which has attended the works already executed in the Port of Dublin gives great encouragement to the Corporation to proceed in the same course. There are few, if any, similar cases of a bar and entrance channel to any harbour being increased in depth like that of Dublin, viz.:—about 7 feet in thirty years, and I think great credit is due to those who designed, as well as those who executed works which have achieved so important a result."

Such is the testimony of men well acquainted with the difficulties to be overcome, and the value of the results attained.

From the last Admiralty survey of Dublin bay and bar (Figs. 5 and 9), made by Staff Commander Kerr, in 1873, it appears that there was then a channel across the bar 16 feet deep at low water of spring tides, being an increase of nearly 10 feet in depth since the construction of the Great North Wall. The very sudden increase in the depth of water on the bar, which took place in the first few years after the construction of the northern wall, was accompanied by what may be termed a progression of the bar eastwards, as if the sand removed from the bar was driven over its ridge into deep water. This will be better understood by a comparison of the sections across the bar in 1819 and 1856, from which it will be seen that there is a considerable distance between the eastern slopes of the bar in those respective years (Fig. 9). The eastern slopes in the years 1856 and 1873 seem, however, to be virtually identical, proving satisfactorily that the fears, sometimes entertained of the bar reforming in deep water further eastward, are practically groundless.

Having thus reviewed the past history of the improvement of the entrance to the harbour, the question naturally arises, what are the prospects of further improvement? The Author believes that there is a fair promise for the future, seeing that the forces which have been so successful in removing the bar are still at work, and their resources are far from being exhausted. From a comparison of soundings taken at intervals since 1819, it is evident that the depth of water on the bar is still increasing (Fig. 8), and it seems

probable that, within the next ten years, there will be a channel across it with a depth of 18 feet at low water, without resorting to any additional or special works to gain this end. Should such a result be attained, and the improvement in the channel up to the quays keep pace with that on the bar, the port of Dublin will, ere long, pass out of the list of tidal harbours. The present area of the harbour inside the Great North and South Walls, or what may be called the scouring basin, is about 2,350 acres. Of these, about 700 acres are covered to the full depth of the tide, the remaining 1,650 acres being strand, averaging about 4 feet over low water of spring tides.

The total capacity of the harbour at high water of spring tides is, therefore, 29,807,485 tons (say 30,000,000), its capacity above half tide level being 19,010,828 tons (say 19,000,000), and below that level, 10,796,657 tons (say 11,000,000). These quantities do not include any allowance for water running through the harbour to and from the Sutton channel north of the Bull island; they are, therefore, probably rather below, than in excess of, the actual quantities.

As previously stated, the alteration in the channel through the bar is due to the water discharged from the harbour on the last half of the ebb. It would, therefore, seem probable that any increase in the quantity discharged in that time may be expected to produce a corresponding increase in the depth of water on the bar. Now such additions to the capacity of the harbour below half-tide level, or what may be termed its effective scouring capacity, are constantly being made; for, as the strand inside the harbour is stripped on the ebb tide, there is a rapid flow of water towards the navigable channel, which brings with it considerable quantities of sand. This action, jointly with the dredging of ballast from that part of the harbour, is gradually lowering the north strand, and thus increasing the tidal capacity in the manner most to be desired. It may be urged, that allowing the sand from the north strand to be carried into the navigable channel is bad economy, and that it would be preferable to construct low training walls, with gaps at intervals, along the north side of the channel, so as to reduce the silting up, and consequent dredging. The Author believes that the great value of the additional tidal water gained by the lowering of the strand more than compensates for any increased dredging which may be necessary, while the absence of anything in the form of a training wall is of great advantage to the navigation of the harbour. For each foot that the strand may be hereafter lowered the tidal capacity of the harbour will be increased by about

2,053,543 tons of water—a large percentage upon the present effective scouring capacity. It will thus be seen that the scouring capacity of the present basin is far from being exhausted. Should it appear, however, at some future time desirable to increase the area of the scouring basin, with the view of largely increasing the tidal capacity of the harbour, Mr. Giles's proposal for an embankment between Sutton and the North Bull island, might be carried out, thus converting the North or Sutton channel into a tidal reservoir (Fig. 6). But any such increase in the area of the basin must be undertaken with the greatest caution, and should not be attempted till the maximum results attainable from the present basin have been reached. Any one who has witnessed the rush of tidal and river water through the entrance under existing circumstances, will fully appreciate the dangers of a large increase in the velocity; and this must inevitably follow any great increase in the tidal capacity of the harbour.

In view of the difficulties overcome in improving the harbour entrance, it is only natural to enquire what are the dangers which beset the maintenance of the deep water channel across the bar? The re-formation of the bar might be due to two causes, reclamation within the harbour, and also reclamation outside the harbour. Reclamation within the harbour must be jealously guarded against as an encroachment on its tidal capacity, since the maintenance of the channel over the bar depends upon the tidal capacity of the harbour. For this reason any attempt to make ground within the harbour by excluding tidal waters should be resisted, unless it can be shown that some counterbalancing advantage will be gained by the port. The history of marine engineering in England and Ireland is not without instances of injury done to harbours by the exclusion of tidal waters, consequent on the reckless reclamation of land.

But the dangers to Dublin harbour are not confined to reclamation within the harbour. Reclamation outside is almost equally objectionable. The North and South Bulls in Dublin Bay may be looked upon as great reservoirs for sand. There is evidence to show that large accumulations of sand have taken place upon them during the present century, especially upon the North Bull; and, as a natural result, there has been a gradual progression of the low-water mark farther out to sea. Reclamation of any kind which would reduce the area of these sand reservoirs must be looked upon as antagonistic to the interests of the port. Assuming an embankment formed along the margin of the North or South Bulls, the result would be, that the sand which is now yearly

washed far up into the bay would be deposited outside this embankment; the low-water mark would be carried rapidly much farther out to sea, and would form, in all probability, a serious obstacle to the maintenance of the deep-water channel across the bar.

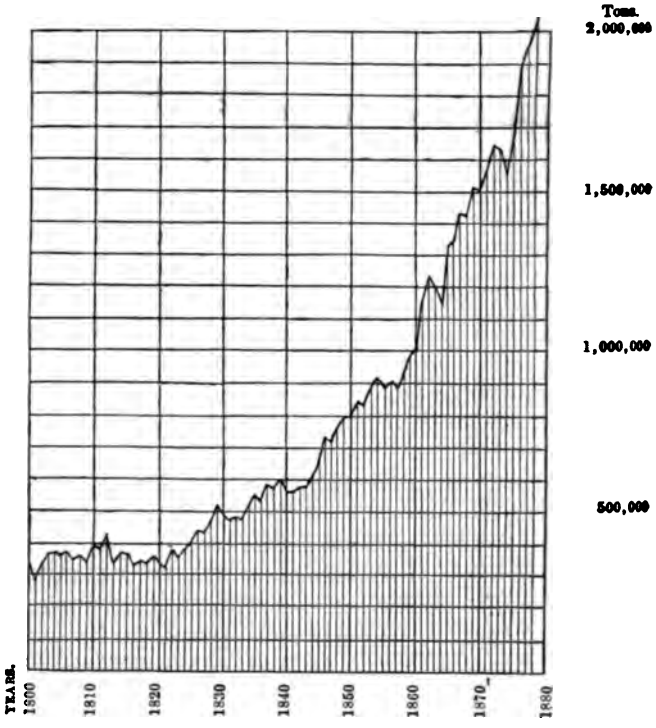
No doubt it may be said that nature is steadily doing this; but such a fact does not afford any argument for assisting it in its work. A time may come when the encroachment of the North and South Bulls upon the entrance to the harbour will form a question of vital importance to the port, and perhaps necessitate the extension of the Great North and South Walls farther seaward. It is to be hoped that, when such a contingency arises, means may be devised for the preservation of the port which will form a worthy supplement to the work of those distinguished engineers who have done so much for its improvement. In the meantime, it is clearly the duty of those charged with the care of the port to postpone the evil day by every means in their power.

The Author believes the foregoing objection to external reclamation forms one of the strongest arguments against Mr. Rennie's proposed southern reservoir (Fig. 2). His proposal to enclose 1,300 acres of the South Bull would necessarily have excluded the deposition of sand within that area, and have forced it to accumulate to the eastward of his embankment. In all probability such a result must have been injurious both to Dublin and Kingstown harbours, and to the entrance of his proposed ship canal.

However successful the results have been in Dublin, it is not to be inferred that the same method is capable of universal application. In no branch of the profession is so much variety to be found as in marine engineering; and among questions connected specially with it, that of the improvement of tidal rivers, and the removal of bars, stands pre-eminent in this respect. There are numerous examples of successful attempts to remove bars, but scarcely two that can be cited as even similar in their leading details. Different causes have produced the bars; some being due to the action of the sea, while others are formed by the deposit brought down by the rivers themselves. There are endless variations in the set and force of the littoral currents, which must necessarily affect the mode of treatment adopted; while another most important difference arises from the relative value of the upland and tidal waters—a question which must be carefully investigated in each particular instance. Cases have occurred where the upland waters being insufficient for the removal of a bar, and local circumstances preventing the introduction of tidal water in

sufficient quantity to effect this object, it has been considered necessary to dredge away the bar, and construct an entrance in deep water by running out piers. Although the results in Dublin may not equal in magnitude some of the improvements carried out of late years in such rivers as the Danube and Mississippi, yet, from an engineering point of view, the improvement of Dublin harbour entrance ranks second to none. There is no other example, so far as the Author is aware, of the construction of an artificial estuary for scouring purposes which has proved so successful. The value of the results achieved, from a commercial point of view, will perhaps be most clearly understood by an inspection of the curve of registered tonnage of vessels entering the port during the present century. It will be observed, that since the year 1820 the tonnage has been steadily on the increase; and the Author submits that the improvements made in the approach to the port were the immediate cause of this great extension in the trade.

CURVE SHOWING THE REGISTERED TONNAGE THAT ENTERED THE PORT OF DUBLIN FROM THE YEAR 1800 TO 1878.



Dublin Harbour owes much of its improvement to dredging, as well as to scour (Fig. 9). In fact, from Carlisle bridge to within about 1,000 feet of Poolbeg lighthouse, the improvement in the channel is solely due to dredging, the effect of scour being inappreciable; while to the eastward of this point and across the bar no dredging has been required.

In referring almost exclusively to this latter section of the approach to the port, the Author has no wish to depreciate the great advantages which the port has derived from dredging; but he adopted this course for the following reasons: First, because he believed a description of the dredging machinery used by Mr. Stoney, M. Inst. C.E., in Dublin Harbour would afford ample data for a valuable Paper in itself, especially in view of the size of the plant employed, which is probably unsurpassed in any other port; and, secondly, because it appeared to him that dredging is rather a question of the application of sufficient mechanical power, while the improvement of the bar by artificial scour is essentially a triumph of Civil Engineering in its more restricted sense, and forms a noble example "of directing the great sources of power in nature for the use and convenience of man."

The Paper is accompanied by several maps and sections, from which Plate 1 has been compiled.

[Mr. BATEMAN,

Mr. BATEMAN, President, happened to know something of Dublin Harbour, and it appeared to him that there were some little inconsistencies in the Paper. The Author attributed the improvement which had taken place to a great extent to dredging, but how did he distinguish between that which he called artificial scour and dredging. Was not the one the consequence of the other? Again, he had said a good deal about the danger of inside reclamation. Now the North Bull had added very much indeed to what was equivalent to reclamation, for reclamation was simply the exclusion of tidal water and the deposit of sand, which had taken place both to the east and the west of the Great North Wall, and had excluded a considerable amount of tidal water, at the same time that, according to the Paper, the bar itself had been removed farther out to sea, and a greater depth had been acquired over it. Altogether the improvement of the harbour had been very conspicuous.

Captain CALVER, R.N., agreed with the Author in nearly every particular. As to the effect of interior dredging upon the improvement of depth over the bar, he might mention, that dredging in the channel between the Poolbeg lighthouse and the city of Dublin would remove the obstructions in the channel, but would do little towards the reduction of obstructions outside the works. That was due simply to the scour, and the scour depended upon the quantity; and unless the dredging in the channel between the Poolbeg lighthouse and the city had lowered the surface, it could not add to the quantity, and consequently could have had but little effect in bringing about the improvement. The degraded or low portion of the north wall was a special feature of Dublin Harbour, and it struck him that it showed the acumen and professional knowledge of those who projected the work, and he should regret were its principle interfered with. It was exactly adapted to meet the special circumstances of the case, which were that there were only three hours set towards it and nine hours set away from it. He was favourably inclined towards the Author because of his insistence upon the value of tidal water, for he could not help remembering that about thirty years ago he was the best abused man in the north of England because he advanced similar views. It was satisfactory to find the Author, as the result of experience gained in Dublin Harbour, laying great stress on the value of that feature. The Author's remarks about Mr. Rennie's proposal for a reservoir south of the Poolbeg pier were particularly good, as were others also respecting the gradual enlargement of the interior basin by a natural process, and the undesirability of a

training wall on the north side of the channel. With regard to the converging form of the artificial works at Dublin, he might refer to his "Proposal for the Improvement of Southwold Harbour" (with a plan), submitted in July 1844, in which he advocated a concentrated ebb and a diffused flood for keeping down a bar—a movement which had been so efficacious in dealing with that of Dublin. As a matter of fact he was not acquainted with the works at Dublin at that time, but his object in making this proposal was to keep down a bar, and his idea was that the ebb should be concentrated by converging works, so that there should be a dispersed flood over the region of the bar. He believed that, in the case of Dublin Harbour, there was a concentration of the filaments of the ebb out as far as the bar itself; that was, that the filaments of the ebb converged to a point about the bar or outside it; while it was manifest that the flood would be diffused over the same region. That seemed to him to be a most desirable principle wherever it could be accomplished. He should like to hear from the Author if the conditions of tide were such as he had described. If they were, it would go far to account for the improvement which had been effected in the depth over the bar of Dublin Harbour.

Mr. ABERNETHY, Vice-President, said the Paper referred to a subject of great importance to engineers, namely, the improvement of navigable rivers, and the removal of impediments at their entrances in the form of bars. The Paper described the general results of the construction of two works of considerable importance, namely, the North and South Walls, the first constructed, he believed, so far back as the year 1796, and the latter in 1825. The objects sought to be attained, more particularly by the North Wall, was, first, to prevent sand being carried by north-easterly gales into the harbour; and secondly, to provide a reservoir of tidal water near the entrance, to be discharged at the point between the pier heads, where of course a considerable velocity would be attained. He believed that, about the year 1801, Captain Bligh, of the Royal Navy, proposed the construction of a wall parallel to the South Wall, and the removal of shallows within the harbour by manual labour, dredging being at that time unknown. The Tidal Harbour Commission expressed a strong opinion that, if these works had been carried out, in all probability the harbour would, at the time the Commission reported, have been improved to a much greater extent than it had been. The construction of the North Wall prevented the accumulation of sand within; but, according to the Paper, it had resulted in an accumulation of sand without, and the gradual progressive shifting of the low-water

line seaward. He regarded that as a feature which, if it went on, would eventually necessitate a considerable extension of the existing works to preserve the harbour entrance. With regard to the scour, it was manifest that the greater portion of the ebbing current between the North and South Walls passed off at an early period of the ebb; and no doubt it was true, as the Author had stated, that the erosive action of the current was greatest at the period of half ebb and beyond half ebb. Therefore a large portion of the tidal water passed off from that large area at a period which was not effective as a scour upon the bar. For his part, he was of opinion that it would be necessary, in order to prevent the consequences of the gradual extension of the low-water line seaward, resulting from the construction of the North Wall, to project the walls farther seaward; and that the Tidal Harbour Commission were right in their opinion that, if a wall had been constructed (allowing a sufficient width of channel) parallel to the South Wall, and the additional volume of tidal water required for the purpose of scouring had been provided by dredging the entrance channel, as in the case of the Tyne and the Clyde, a better effect would have been produced than by the large reservoir enclosed between the North and South Walls, which could only produce an extraordinary current between the pier heads, which ceased before it reached the bar. He thought attention should be directed to the construction of works which would tend to increase the tidal volume, and at the same time to prolong the action of the outgoing currents from the period of half ebb towards low water.

Mr. Hyde Clarke had listened with great interest to the Paper, because it dealt with a subject in which he had himself been engaged many years ago. The principles enunciated by the Author were held by some persons, as was stated by Captain Calver, a long while ago, amidst a great deal of unpopularity. They were, after all, the principles which must dominate such works. As far as possible, engineering must help nature. He gave attention to the subject as far back as 1836; and it was in reference to facts which the Author had so strongly called attention to, that he proposed a different mode of dealing with it, namely, by cutting through the neck of the Hill of Howth, for the purpose of getting rid of that trouble to which Mr. Abernethy had referred—the advance which was then shown at the North Bull, and which had continued ever since. That was surveyed about 1838 or 1839, and the proposal was brought before the Ballast Board, but though there was a good deal of correspondence, it was not received with favour. He merely

referred to that as an incident in the history of the subject which the Author had not introduced, thinking perhaps that it was too trivial, though in fact it supported some of the principles which had been brought forward in the Paper. The construction of the North Wall was well deserving of consideration, for he had always thought that in heavy gales it would be advantageous to keep down the level of the neck of a pier, or even to cut through it, so as to allow the shore set to help the scour. Looking to the great progress which had been made since that time in the channel, it was satisfactory to see that there had been so much help given to navigation. He agreed with the President that it was difficult to decide between the question of dredging and of scour, but he thought that when there was dredging in the first instance, the scour came in to help afterwards. He should be inclined to modify, to some extent, the Author's views with regard to the commerce of the port. He thought the increase of that commerce was due to other circumstances besides the improvement of the harbour; but where the improvement of the harbour had told, was in allowing a larger class of vessels to enter. He had not followed up the subject for a great number of years, but formerly he took part in these discussions on hydraulic engineering, as the Transactions of the Institution would show. He was, however, in a position, like many others, to bear his testimony to the value of the observations recorded in the Paper, and also of the principles to which the Author had directed attention.

Mr. SHOOLBRED remarked, that the success of the operations described had for himself a special interest, from the fact, that a great deal of that success was apparently due to the advice of Mr. Giles having been obtained in the construction of the works. The works executed presented certain features, which that gentleman had possibly become acquainted with in another centre of tidal operations, the estuary of the Mersey and the river Mersey itself; both of which localities had been most carefully surveyed by him. The peculiar feature of the North Wall, to which so much benefit seemed to be attributed, appeared to have been presented to Mr. Giles's mind by a natural action in the estuary of Liverpool Bay. The main channel of the river Mersey found its way out to sea through what was called the Crosby Channel before reaching the bar. It was there confined, as at Dublin, between two large sand banks, that on the left being formed by what was termed the Great Burbo Bank. As if nature, when getting near the time of high water, wished to relieve itself, the stream formed "swashways" across that bank; and Mr. Giles seemed to

have afforded that safety valve at Dublin by lowering the level of the seaward termination of the North Wall, thereby allowing the waters, which had been comparatively pent up during the earlier portion of the flow, to spend themselves over the North Bull bank during the latter portion of the flow, and for the first part of the ebb. The Author had alluded to the gradual formation of the Mumbles Bank, as due to the groyne-like action of the elbow of the South Wall. That feature also seemed to present a parallel with a bank which was in course of formation, and which went on increasing, in the Mersey, called the Pluckington Bank. This was due to the groyne-like action of Dingle Point, which deflected the main force of the current to the Cheshire shore, allowing the detritus and sand to be deposited along that bank, in a way similar to what the Author supposed had caused the gradually-increasing bank of the Mumbles. The Author had spoken in rather warning terms of the enclosure of the two natural reservoirs of sand, the North and South Bulls. Mr. Shoolbred might also refer to an instance, which, perhaps, bore out that warning, namely, the extension of the river walls out into the estuary of the Seine. The result of that was, that the required inflow of the tidal water was much smaller, and the sand banks had gradually protruded out into the bay—tidal-borne sand which had originally found its reservoirs in the reaches higher up—until by these external accumulations the existence of the port of Havre was threatened. He might be mistaken in his supposition, but it appeared to him that the unsuccessful issue of those works, as far as the estuary was concerned, afforded a warning with regard to other cases.

Sir JOHN COODE said the Paper was interesting, because it embraced a history of the port for one hundred and sixty years, and recounted, step by step, every portion of the work that was carried out, and the reasons which prompted the particular recommendations, and the successful results which followed in every stage. He would be exceedingly sorry to say one word that could be thought to detract from the credit of those who had carried out the works at Dublin. He only wished to make one remark upon this point, and that was that the physical conditions were peculiarly favourable to the enclosing of a large volume of tidal water. He knew of no other case where the construction of a work of the length of the North Wall would have resulted in the formation of so large a tidal reservoir as that which extended over the whole length of the north strand. He wished to call attention to that, because the conditions were favourable, and the result had been most successful, and creditable to those

who carried out the works. The Author had well remarked that the varying level of the North Wall was a valuable feature, and other speakers had dwelt upon that point with great force. As regarded the general conclusions, he might say that he was almost entirely at one with the Author. They were exceedingly sound, and the Author had evidently considered the whole subject carefully; but it was to be regretted that he had not said whether or not there were any occasional changes of depth upon the bar. He should like to know whether, in the varying conditions of sea, particularly in the winter season, the depths of water over the crest of the bar did or did not vary, and, if they did vary, to what extent. The present depth over the bar was, he believed, about 16 feet, and the Author anticipated that there would be a depth of about 18 feet in another ten years. The diagram (Plate 1, Fig. 9) showed the results up to 1873, but it would be interesting to know whether there had been any increase of depth since that time. One thing which the Author called attention to was very important, namely, that there had been no seaward advance of the face of the bar within the last sixteen years. That was an encouraging fact with regard to the ultimate removal of the bar by tidal scour. Perhaps in his reply the Author would give some information upon the subject of increase of depth since 1873. With regard to the outer reclamation, he must say that he agreed with the Author as to the danger to be apprehended from any reclamation of the North or South Bull. Any embankment across those strands would have the effect of causing the low-water line to advance seaward to some extent, but what that might be was rather doubtful. He wished the Author had stated what advance the low-water line, particularly of the South Bull, had made during the last few years. He agreed that there were scarcely any two examples similar in their leading features. If any gentleman, having a particular case before him, sat down to consider, as he had done on several occasions lately, where he could find another case similar in its leading features, he would be sorely puzzled to discover one. The variations in these tidal estuaries were about as great and numerous as the variations in the features of the human countenance. He concurred in what a previous speaker had said, with regard to the Author having claimed rather too much for the improvements in the works, when he said that the advance in the state of the port had been the immediate cause of the great extension of trade. That the improvements had added greatly to that extension of the trade there could be no doubt,

but he did not think that the extension was wholly due to the success of the works. Speaking of the causes which produced bars, the Author attributed some to the action of the sea, and others to the deposit brought down by rivers. Now Sir John Coode did not know of a single instance of a bar formed by river deposit alone, though he knew of many formed wholly and solely by the action of the sea. If any one bar was more likely than another to be formed by river deposits it would be the bar of the Tyne, for the ratio of the flood-discharge in that river to the summer-discharge was larger than that of any other river in this country, about 120 to 1. It was well known that the material of the Tyne bar was sea-sand alone, and what he maintained was, that the material brought down by rivers was deposited towards the head of the tidal water, and little or no material from up country was to be found upon the sites of the bars. The Author had touched upon another important matter, and that was the relative values of upland and tidal waters; that was a question which must be carefully investigated in each particular instance. He did not agree with those persons, of whom he believed there were a great number, who said that the tidal water was everything, and the fresh water nothing. The quantity of fresh water in the Liffey was infinitessimally small as compared with the tidal water, and, in fact, the value of the fresh water there as a scour might be said to be nil. A little further north, however, was a somewhat remarkable river—the Bann. The fresh-water discharge of the Bann, under normal conditions, was somewhere about two-and-a-half times that of the tidal water. It was fed from the great Lough Neagh, which covered an area of 150 square miles, and the quantity of fresh water flowing down was certainly two or three times that of the tide. The Danube was an extreme case. The Black Sea was a tideless sea, and the navigation of the Danube was dependant solely on the fresh water. Therefore, the effect of the fresh water in rivers must not be disregarded. In many rivers the navigation was as dependent on the quantity of fresh water as on the quantity of salt water. To revert for a moment to the question of the formation of bars, he would like to mention in support of his view that they were formed almost entirely by the sea, some rivers illustrating this in Australia. At the Swan river, on the coast of Western Australia facing the Southern Ocean, with very little tide, there was a bar of the worst possible description; while the Yarra, at Melbourne, which discharged into a sheltered embayment at the head of Port Phillip, though it had a rise of tide precisely the same as the

Swan river (about 2 feet) had no bar, simply because it was in a sheltered position, and there was no heavy wave action to throw up the material to form a bar.

Mr. GILES, M.P., said, it was gratifying to him to hear that the works carried out by his father, upwards of fifty years ago, had been so successful in tending to the improvement of Dublin Harbour. He regretted that he did not know the locality, but he could conceive that the North Wall was partly designed with a view of narrowing the entrance, so as to get a scour to push the bar farther seaward, and to enclose a large estuary by which the tidal water might be impounded; and that the making of a tidal reservoir of the northern part of the North Bull was only carrying out that idea to a farther extent. Whether the embanking of that portion of the North Bull, and converting it into a tidal estuary, would have had the effect, as was supposed by the Author, of driving the low-water line farther to sea, he considered doubtful. At all events, the Admiralty chart showed that there had been little advance in the low-water line for fifty years. He thought some action was going on within the line of the north strand, which, if carried to any great extent, would prevent the deepening of the water over the bar. The Admiralty chart showed that a large area had been enclosed. Now, every acre of land which was enclosed there would shut out so much tidal water, and to such extent would be a disadvantage to the scour. Perhaps the cheapest way to improve the scour would be to dredge out mud over that area down to low-water level. Of course, as Captain Calver said, if it was dredged out below low-water mark there could be no scour below that level. He also thought that the positions of the North and the South Walls must have a useful effect in assisting vessels to enter the harbour, because they resembled what had been adopted at the mouth of the Tyne, and formed a sort of wave trap. He could not agree with Sir John Coode, that bars were never formed by fresh water; but in this case he could conceive that the small amount of fresh water coming down that narrow stream could have little effect in scouring, or driving the bar farther to seaward, when the entrance through which the tide must pass was 100 feet wide.

M. BERGERON considered the Author was very modest in suggesting a period of ten years as necessary for reducing, by 2 feet only, the level of the Dublin bar. He would show that it was easy and simple to increase the depth of water over the bar, not only 2 feet, but, perhaps, 5 or even 10 feet—not in ten years, but in a few weeks. He was surprised to hear that it had been possible to determine

by such a precise number of feet the depth of the sea on the bar of Dublin. From personal observations in several harbours along the Channel—for instance, at Boulogne, Calais, and Dunkirk, on the French coast—he was almost certain that the section of a bar across the mouth of a harbour was constantly modified by the current of the tide or the violence of the waves. M. Plocq, engineer-in-chief at Dunkirk, once measured the quantity of sand which had accumulated at the end of the piers after a violent gale, which lasted two or three days, and found it to be more than 40,000 cubic yards. Every year it happened that the mail boat at Calais could not enter the harbour at low tide, because the north-east wind had prevented the current of the flood, which carried an enormous quantity of sand, from running with its usual speed along the coast. The stoppage of the current by the long jetties, which advanced far into the sea, let the sand fall to the bottom; and the bar was sometimes increased by several feet at its upper level, after a week of strong north-east wind. The only remedy for such evils was the use of a large reservoir, in which water had been accumulated at high water of spring tides, and which was emptied through sluices with a rush in less than half an hour, at the lowest level of the tide. He considered the harbour of Dublin as an immense storage reservoir, from which, as the Author said, eleven million tons of water passed over the bar during three hours at every tide, and he was surprised that such a current was unable to lower the bar more than 2 feet in ten years. He would now explain how it was possible to increase the effect of the sluices or of any strong current of water rolling over a sand bar. He proposed to use a sort of rake or comb, of which the points or the teeth were covered by small tubes of flexible indiarubber hose, through which jets of water were forced by a pump. In this contrivance a horizontal cast-iron pipe was suspended by chains at the end of a boat when passing over a bar. At the bottom were small holes from $\frac{1}{2}$ to 1 inch in diameter, about 2 feet distant from each other. At every hole was fixed a flexible hose pipe, of the same diameter, 3 or 4 feet long, hanging vertically by its own weight, which would be increased by some heavy metallic nozzle at the lower end, having its opening close to the surface of the sand bar, which was to be scoured by the jets of water. A vertical pipe was suspended like the horizontal one by a chain to the same transversal pole, and held the apparatus in a verticle plane. By means of a capstan, or any other system, the horizontal pipe could be raised or lowered and fixed at its proper level, in order to have the metallic extremities of the row of small

flexible tubes, or their nozzles, very near the surface of the sand. By a long flexible hose, connected with a powerful pump on the boat, the water was forced through the vertical iron pipe into the horizontal pipe, and escaped through the small tubes at the bottom. Every tube produced a jet similar to that thrown from a fire engine. The water in the pump could be raised to a pressure of several atmospheres, and, in that case, each jet would strike the sand like a nail driven by a hammer, and penetrate it to a depth of several feet. The sand displaced by the jet was necessarily lifted up vertically by the water coming out of the hole, much higher than by an inclined jet. The jets being continuous during the advance of the boat over the bar, produced a series of deep furrows, which were gradually levelled by the current of the tide. In the meantime, the sand raised by the jets, held in suspension in the current at the moment of its highest velocity, was carried a long distance out into the deep sea. A trench was produced on the surface of the bar, in the axis of the harbour. Every time the apparatus was put in operation in the manner which he had described the cutting would became deeper. In less than a couple of hours during the receding tide, which produced eleven millions of tons over the Dublin bar, he was almost convinced that the bar could be lowered by several feet.

In further explanation he said, let a bucket full of clear water be taken, and at the bottom a small jar be placed containing about a pint of sand. Above the middle of the jar, near the surface of the water, at a distance, say of 1 foot, from the sand, plunge the nozzle of a flexible pipe, connected with the cylinder of a common syringe near the bucket, and at a higher level. In that position, if the piston of the syringe was worked the jet of water would, before the syringe was emptied of its contents, wash out all the sand from the jar, and lift it up as high as the top of the water in the bucket by the reaction of the jet. The same effect would be produced on the sand of a bar; and when once put in suspension, the sand would be carried away by the current of the receding tide. The Author mentioned that the velocity of the receding tide over Dublin bar sometimes exceeded 3 miles per hour. M. Bergeron had found from many experiments that the sand remained in suspension in any current having a velocity of more than $2\frac{1}{2}$ feet per second, or less than 2 miles per hour. He might affirm, then, that the receding tide over Dublin harbour bar would be able to carry into deep water all the sand lifted up by the jets of his projected dredger. His system of dredging sandbars was more simple, more economical, and more efficacious than any other. It would be advantageous

to employ Mr. Stoney's dredger inside Dublin harbour, so that the sand raised might be used for building purposes; but it was very difficult, almost impossible, to dredge sand-bars in an open sea. One of the largest dredgers from Glasgow was taken two years ago to Dunkirk, to compete with M. Lavalley's suction apparatus, which was still used at that place; but the contractor was obliged to abandon the work, after a trial which lasted less than a week, on account of the unsteadiness of his boat during a rough sea. The apparatus now proposed, operating upon the surface of a sand-bar with strong jets of water at the moment when the ebb current was strongest, could be applied to every harbour; and it was with confidence that he ventured to submit it to the consideration of the members of the Institution of Civil Engineers.

Mr. VERNON-HARCOURT observed there could be no doubt that the improvement on the bar of Dublin harbour might have been produced much more rapidly by dredging if necessary; but probably the engineers who devised the scheme saw no advantage in a very rapid increase in depth over the bar, when there was no corresponding dredging inside the harbour. Of course by deepening a channel by artificial scour the effects would not be altered as long as the general conditions of the site remained the same, whereas in many cases dredging had to be constantly repeated. The effects produced by artificial scour were in a great measure due to the peculiar set of the tides, the tide setting eastward from the harbour when the incoming tide would be from due west; but he supposed this was partly due to the tide coming from the west along the south coast, and then eddying round by the South Wall. With regard to the North and South Bulls, he agreed with the Author in thinking that it would be undesirable to reclaim those portions—not so much, perhaps, because they were reservoirs of sand, but because they were reservoirs of slack water, and wherever there was slack water there must be a deposit of sand. Whether, when they were reclaimed, the sand would equally deposit in front would depend very much on the set of the tide. If eventually they were reclaimed, or when (as was certain to be done by nature) they rose above the high-tide level, it seemed probable that the sand would be first washed into the channel from the south, as formerly, and that afterwards the South Wall would have to be extended to remedy the evil, and then the North Wall prolonged in order to keep the channel open. He did not think there could be two opinions on the subject of reclamation inside the harbour. To diminish the tidal capacity within a harbour was the worst thing that could possibly be done. He might refer

to an instance of that kind upon the same coast—the harbour of Wexford. That harbour was favourably situated with regard to the English coast, and it ought to be about the third harbour in Ireland in importance. The county of Wexford was nearer Pembrokeshire than Dublin was to Anglesea; and Wexford harbour was much more favourably situated by nature than Waterford for communication with Milford Haven; but unfortunately, like Dublin, it had a bar at its mouth. The bar was due to sand from the sea, which, in drifting northwards, was washed into the harbour. The river Slaney, which flowed into the harbour close to the town of Wexford, did not materially contribute to the formation of the bar. Certain works had been carried out from time to time for improving the bar, but the Wexford Harbour Commissioners had not the same amount of money or the same power of doing the work as was possessed at Dublin. About thirty years ago the harbour was 8 miles long from north to south, by 3 miles wide from east to west. Half of that had been reclaimed, and the bar had since been increasing; the tidal capacity had been diminished by about a half, and the channel had been varying from time to time, sometimes going towards the north, and sometimes towards the south. The Dogger bank outside the harbour had increased considerably, and overlapped the two points at each side of the entrance to the harbour. Reference had been made by the Author to the Danube and the Mississippi; they were in some way comparable to Dublin, but they brought down the silt which formed the bar at their mouths, and also had to provide their own scouring action. The works had been somewhat similar; walls or jetties had been projected out on both sides. There was one point of similarity between the Mississippi works and those at Dublin. Some years ago it was proposed to get over the difficulty of the shallowness of the mouths by making a ship canal. That was approved of in 1873 by a Commission of engineers, but the president alone, Major-General Barnard, dissented from the scheme, and Congress eventually did not sanction it. In 1875 it was decided to use the South Pass forming one of the mouths of the Mississippi, and to run out jetties to improve that channel. The work was begun in June 1875; and in 1877 it was stated, in a report that appeared in the Journal of the Franklin Institute, that the channel between the jetties had been improved from 8 to 20 feet, and the channel across the shoal at the mouth from 15 to 20 feet at the sides and 30 feet in the centre; and that the Gulf in front of the channel had increased in depth. With such results he thought it must be acknowledged that the jetties and other works for contracting

and deepening the channel were the most remarkable achievements of modern times in river engineering.[1]

Mr. G. HIGGIN thought that the displacement of sand depended upon a current existing to carry it away when displaced, or, in other words, upon the scour, which again was dependent upon the velocity of the water at the bottom of the channel, this being the most important element in dealing with the scour of rivers, or entrances to tidal harbours. In the interesting and unique experiments carried out under the direction of Mr. Bateman, President, in the great rivers of South America, certain new laws were discovered with regard to the movement of large masses of water. One of these was, that the surface velocity of water at a given inclination varied directly as the depth of the channel; and another (although not stated by the President's assistant, who published the account of the experiments) was, that the bottom velocity of water varied directly as the square of the depth. That was an extremely important law with regard to the scour of rivers, because the scour depended upon the bottom velocity. He had made some calculations to show what the effect of the law would be in the case of Dublin harbour. It was, he believed, generally supposed that the scouring effect of the tide took place principally at the second half of the ebb, because probably at that time the surface velocity was usually the greatest. But he thought it was almost certain that the scouring effect was not greater, although the surface velocity might be higher. The entrance between the two walls of Dublin harbour was about 1,000 feet wide. The depth at low water was 15 feet, and at high water 27 feet. If at the turn of the ebb, with 27 feet depth, there was a surface velocity of 176 feet per minute, or say 2 miles per hour, the

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[1] Sir Charles Hartley, M. Inst. C.E., the British member of the advisory board of 1875, of which General Barnard was the President, has recently heard from Captain Eads, M. Inst. C.E., to the effect that, between December 1878 and June 27, 1879, the channel on the bar had been deepened from 22 feet to 28 feet. With the exception of a length of 350 feet, there was a continuous channel through the jetties over 30 feet deep, the least width of the 26-feet channel being 205 feet. At the head of the Pass there was a depth over the shoal of 24½ feet, but as soon as there was a flood in the river this would be increased to 27 or 28 feet. From more recent information it appears that the South Pass Jetty works have been practically completed. When the operations were commenced, the entrance to the Mississippi was by the South West Pass, where a depth of 17 or 18 feet on the bar was only maintained by constant dredging. Now there is a depth of 33 feet over the bar between the South Pass Jetties, against 7 feet before the works were begun. When the South Pass was adopted, the other entrances were closed.—SEC. INST. C.E., July 28, 1879.

bottom velocity would be 69 feet per minute. The discharge belonging to those two velocities would be about 3¼ million cubic feet per minute. Supposing the same discharge to continue when the tide fell to 21 feet, the surface velocity would be increased to 241 feet per minute, and the bottom velocity to 72 feet. When the tide fell to 18 feet, the surface velocity would be 290 feet per minute, and the bottom velocity only 75 feet. Thus, while the surface velocity had increased 65 per cent., or say from 2 miles to 3⅓ miles per hour, the bottom velocity had only increased 10 per cent. It seemed probable, therefore, that the scouring effect of a mass of water flowing out through a channel was not greater at half or three-quarters ebb than it was at the full tide; and that it was erroneous to suppose that there was a greater scouring power at the latter half of the ebb than at the commencement, although the surface velocity might be much greater. This had an important bearing on the question of scouring, because it was of no use to raise sand from the bottom without a sufficient current to carry it away into deep water.

Mr. J. Wolfe Barry said, it would be interesting to have some accurate or measurable data by which to judge of the pressure which would be required to move sand or other substances by M. Bergeron's system under different heads of water; perhaps M. Bergeron could give some figures by which a correct idea might be formed of the power needed to raise the material forming bars to certain definite heights above the present surface. Engineers would then be able to judge whether there was a chance in any particular instance of sand or shingle being raised into such currents above the bottom as would enable it to be carried away sufficiently far. At first sight the system appeared to promise well; but at present there were no data to judge of the expenditure of power required to produce jets of sufficient force to give a valuable result. He should imagine that the depth of water would be a material factor in the calculation. Operating in shallow water, some considerable portion of the power, he presumed, would be exerted in forming waves on the surface, so that the full amount would not be exerted on the bar.

Mr. Rawlinson, C.B., said, if what Sir John Coode had said were true, that the principal power forming bars was the sea, engineers should be careful how they came to the conclusion that dredging, or operations by vertical jets of water, would be of any permanent benefit. Rivers and harbours had no doubt been improved by sea walls and by dredging; but, so far as he knew, no harbour had been permanently improved if the trade of the place

had not been sufficient to continue the first operations, without which nature would soon bring the place back into its original condition. A return showing the sums spent on Irish harbours, and their present condition, would not be encouraging. Where a channel had been formed by dredging, and where there was a traffic continuously working along it to pay for dredging, the tendency was to keep it to the depth established; and the greater the traffic the better the channel was kept open. That was the case with the channel leading out from Liverpool. He could not imagine that anything but a temporary effect could be produced on such channels by artificial flushing. So enormous was the amount of sand stirred up, and held in suspension, at every spring tide flowing into and out of the Mersey, that the authorities might well despair of keeping those channels open by artificial means. He was not aware that vertical jets of water had been used in the Mersey channels; but formerly steamers were sent in and out at half tide, dragging large harrows along the bottom of the channel; but that, he believed, had been given up. As had been pointed out, the velocity at the bottom of a deep current was smaller than that at the top. Just as the top side of a wheel on a road moved faster than the bottom, so the upper surface of flowing water moved more rapidly than the bottom; in fact, it formed a series of cycloids, like a wheel and axle in forward motion. For a time the bottom became the fulcrum, and was even making an under tow. It had been said, with regard to the Straits of Gibraltar, that there was always a top flow from the Atlantic into the Mediterranean, and an under flow from the Mediterranean outward. He believed in the former, but not in the latter. There might be an apparent under flow when the sounding line went down, but it was not a true flow. If Dublin harbour was to be improved and maintained, it would have to be, as heretofore, by dredging within the river and maintaining the works that set the outflow of the tidal water on to the bar. Any isolated temporary dredging on the bar itself would be money thrown away, unless the increasing trade of the port could afford the annual cost of continuous dredging.

Mr. BATEMAN, President, said, that Mr. Wolfe Barry (as far as he had understood him) had asked for some definition of the power, by which he supposed he meant the velocity, necessary for moving material at the bottom of a river. The observations of Mr. Higgin in regard to experiments carried out on the river Paraná, in South America, had pointed to the fact that the velocity at the bottom of a river was greater than had been hitherto supposed when the tide was at full flow, and that the first ebb of the tide was as powerful,

or more powerful, upon the bottom than the latter half of the ebb. He rose, however, for the purpose of referring to a statement that no alteration had taken place since 1819, when an accurate survey of the Bay of Dublin was made by the late Mr. Giles. He had had to consider the question of the reclamation of a large portion of land to the north-east of the North Wall, and sections had been taken, commencing at the North Wall, for every ½ mile, six in all, extending over 2½ miles. At the first and second sections (one being exactly at the North Wall), there had been, in the interval between 1819 and 1865, an accumulation of sand of 8 feet and 8 feet 6 inches in depth, and the margin of low water had been pushed upwards of ½ mile further to the south. The accumulation gradually decreased going northward, and the margin of low water more nearly approached what it was many years previously, and, finally, it terminated altogether. But a much more important point was that the sand which had accumulated to the north or north-east of the North Wall had formed an island at low water, which was nearly covered at spring tides; and the consequence was that a large portion of the water on the ebb found its way through an opening, crossed by a wooden bridge, at the north-west end of the North Wall, so as to increase the quantity of water upon the latter part of the ebb which was brought down by the Liffey. That added to the scour of the main channel by which ships were navigated, and to the scour upon the bar, which had certainly been moved considerably to the east by what the Author called artificial scour. How he discriminated between artificial scour and the operation consequent upon dredging he did not know. He believed that the increased depth was principally due to the operation of dredging, which had enlarged the channel materially between the point of the North Wall and the city of Dublin. He merely mentioned these facts in order to prevent the supposition that no accumulation, or no material alteration of the margin of low water, had taken place since 1819.

Mr. Griffith, in reply, said the President in his opening remarks asked the question how the improvements due to scour could be distinguished from the improvements due to dredging. That could easily be done, for the improvement due to scour was almost entirely outside the harbour, to the east of Poolbeg, while dredging was only effected inside the harbour. Before 1860 the dredging in the Liffey was comparatively insignificant, and was chiefly devoted to deepening the channel. As Captain Calver had clearly pointed out, such dredging operations would do little towards increasing the depth of water on the bar. In the meantime, however, there had been an increase of 7 feet in depth on the bar, and there could

be no doubt that this improvement was due to the Great North Wall. Prior to its construction the ebb of a spring tide attained a velocity of 1¼ mile per hour across the bar; while at present it reached nearly 3¼ miles, showing an increase of about 2 miles per hour. As these alterations in velocity had produced the improvement on the bar, he felt justified in using the term "artificial scour." He had hoped that in the course of the discussion some data would have been given as to the most efficient velocity for scouring. He did not believe that very high velocities were efficient. Several instances might be named in which high velocities were attained, and yet the scour was a failure. Since 1860 the dredging plant of the port of Dublin had been greatly increased, and considerable areas of strand within the harbour had been dredged away. This, of course, had added to the tidal capacity of the harbour, and perhaps in some measure accounted for the acceleration in the scouring of the bar observable in the most recent soundings. There appeared to be some misconception regarding the accumulation of sand on the North Bull. That accumulation was outside the harbour, and was in no sense equivalent to internal reclamation. He used it as an argument against external artificial reclamation. It was a process of natural reclamation, and it should not be assisted. It had been estimated from the sections to which the President referred, that this accumulation amounted to 125,000 cubic yards per annum, or 5,750,000 cubic yards between 1819 and 1865, while the low-water mark close to the Great North Wall was more than 3,000 feet farther out than in 1819. There was, however, no accumulation of sand west of the Great North Wall; so far from this being the case, the strands within the harbour were materially lower than before the wall was constructed. Captain Calver had surmised that the ebb was concentrated and the flood diffused at the bar. He thought this view correct. It had often occurred to him that the ebbing waters from the North and South Bulls exercised a useful flanking effect on the ebb from the harbour, tending to keep the issuing stream concentrated for some distance beyond the entrance. Of course this effect would be absent on the flood tide. He could not share in Mr. Abernethy's admiration of Captain Bligh's scheme. That scheme was entirely devoted to the improvement of the harbour. Captain Bligh had no intention of improving the bar; in fact, he stated that the bar formed no obstruction to navigation, and that few ports were comparable with Dublin for ease of approach. Mr. Abernethy had expressed his concurrence in the opinion of the Tidal Harbour Commission that Captain Bligh's North Wall would have been of more benefit than the present tidal reservoir. Mr. Griffith believed that what the

Commission stated was, that the harbour of Dublin would have been in a better state if Captain Bligh's wall had been carried out than it was when they reported in the year 1846. They did not mention the bar, but confined their statement to the harbour. Had Captain Bligh's proposal been carried out, the maximum tidal capacity of the port would have been only 10,000,000 tons instead of, as at present, 30,000,000 tons. Mr. Hyde Clarke had referred to certain proposals which were not mentioned in the Paper. There were many such omissions, for it seemed desirable to restrict the Paper as far as possible to the improvement of the bar, and thus limit the discussion to that one point. Both Mr. Hyde Clarke and Sir John Coode had objected to a statement he had made as to the connection between the improvements in the approach to the port and the increase in the vessels entering. Perhaps the word "immediate" was a wrong one to have used; his intention was merely to indicate that as soon as the scouring began the tonnage of the port began to rise. He did not mean to say that the improvements in the port were the only cause of this increase. Dublin had become commercially the centre of Ireland, all the railways converging there, and that no doubt was the principal cause of the progress of the port. He was sorry that he could not give reliable information in answer to Sir John Coode's inquiry as to oscillations in the depth on the bar. They were not, he believed, sufficiently marked in the early history of the improvement of the bar to attract attention, and of late years the success of the scour had created a lack of interest in the subject, the result being that soundings were but seldom taken on the bar. The last survey of the bar was that made by the Admiralty in 1873. The progress of the low-water mark of the South Bull was not so marked as that of the North Bull. Mr. Giles' survey did not extend over the South Bull, and the necessary information for forming an accurate estimate was therefore wanting. He could not agree in the non-formation of bars by deposit brought down by the rivers.[1] He had been accustomed to consider that every river forming a delta was capable to a certain extent of forming a bar, and he always viewed the Danube as a case in point. Sir John Coode had dwelt upon the great facilities which Dublin enjoyed for the formation of a tidal reservoir,

[1] The statement in the Paper that some bars are "due to the action of the sea, while others are formed by the deposit brought down by the rivers themselves," was intended to point out that a bar might be composed of materials brought down by the rivers, or of materials washed in by the sea. These features appeared to the Author to have an important bearing upon the design of works intended to improve a bar. He was, however, entirely at one with those who considered that wave action is an essential condition for the formation of a bar.—J. P. G.

as though it depended alone on the construction of the Great North Wall. It should, however, be remembered that the Great South Wall was also necessary—that, in fact, 5 miles of piers had to be constructed to form this reservoir. He was not prepared to express at once an opinion on the details of M. Bergeron's proposal for the more expeditious removal of Dublin bar. In regard, however, to its application to Dublin bar, he might mention that the channel across the bar was materially deeper than some portions of the channel between Poolbeg and the city. Until the river channel was considerably improved, it would obviously be unwise to expend money in attempts to deepen the bar faster. He thought there was a danger in being too eager to deepen the bar by stirring up the sand. It seemed to him possible to overcharge a current with sand—with more, in fact, than it was able to carry—and that as a result a deposit would be formed not far distant. This appeared to have been the case in the first few years of the improvement of the bar, for the rapid increase in depth was accompanied by a considerable progression of the bar. His conclusion was that the current was over-saturated with sand, and being unable to carry it away deposited it as soon as possible.

Sir JOHN COODE wished to say, through the Secretary, with reference to a remark in the reply of the Author, that he considered there was a wide distinction between a "bar" and a "delta." When speaking of a bar, he referred to that kind of comparatively narrow submarine bank, or ridge, with seaward and landward slopes more or less abrupt, which was found to exist at the embouchure of so many tidal rivers.

Mr. STONEY observed, through the Secretary, that the subject brought before the Institution by the Author must be regarded as a remarkably successful instance of the permanent improvement on a large scale of a bar at the entrance of a shallow tidal river. The late Mr. James Walker, who was consulted by the Port Board about other matters in 1861, had been greatly impressed by this, and there was reason for supposing that his views respecting the Tyne piers were influenced by his knowledge of what had taken place at the entrance of the Liffey—an operation so unexpectedly successful that even Rennie anticipated an increase of only 1 foot in depth, in place of the 10 feet which had occurred since 1820. The improvement was still progressing, so that probably the Author's anticipations would be realised, and before the close of this century the bar would, for practical purposes, have ceased to exist. It was a matter of interest to determine who was the author of the Great North Wall, the construction of which had directed

ıe scouring energy of the tidal water across the bar; and it ɔemed singular that there should be any doubt about the original esigner of such a successful piece of engineering. Captain Vashington, R.N., in his report on Dublin harbour,[1] attributed ıe merit to Mr. Crosthwaite, an influential member of the Port ɔoard in the early part of the present century. But the late Mr. [. B. Mullins stated, in his inaugural address as President of the ıstitution of Civil Engineers in Ireland in 1859,[2] that Mr. William hapman, of Newcastle, published an elaborate report in the year 786, and recommended the projection of a pier from the Clontarf hore towards Poolbeg lighthouse, but with this addition, that here should be a bend westward at its outer extremity; this latter ɐeing doubtless intended to form a training wall along the north ide of the river, so as to confine the tidal current within its hannel. Though there might be some doubt as to the authorship f the Great North Wall, there could be none as to its complete ıccess; yet in one respect Mr. Stoney was inclined to think it ıight have been improved. The total length of the wall was ıore than 9,000 feet, of which about one-fourth at the outer end ras submerged at half-tide, and the width of the navigable hannel between this and Poolbeg was 1,000 feet. This peculiar ɔrm of wall was doubtless mainly due to design, but probably lso in part to the greater facility for discharging the stone barges 'hen afloat and thus forming the submerged portion of the wall, han for building the higher part over half-tide level. Conse- uently the progress of the submerged portion would be much in dvance of the finished wall, and the promoters might have been mpressed with the idea that perhaps things were going ahead oo fast. However this might be, he was inclined to think it rould have been equally, if not more, beneficial to have followed ſr. Whidbey's advice and not to have extended the submerged ɔortion so fast. In that case the wall would probably have been ɔompleted to its full height for its whole length, and the entrance ıf the river might have been 200 to 300 feet wider than at ɔresent, and the harbour inside better sheltered from wind and raves. Nor need there have been much apprehension of too great , current for sailing ships at or near high water, for then slack- rater occurred, and large sailing ships would naturally aim at oming up channel with a flowing rather than with an ebbing ide; and though the velocity in the deep hole at Poolbeg might ıave been slightly diminished after half ebb by the greater

[1] *Vide* "Second Report of the Commissioners appointed to Inquire into Tidal Harbours, 1846."

[2] *Vide* "Transactions of the Institution of Civil Engineering, Ireland," vol.vi., p. 9.

width of entrance, it did not follow that it would be materially altered at the bar, where efficient scouring would probably commence a little earlier than at present, and therefore its duration would be prolonged. It might be thought that the principal scour of ebb tide occurred at the last quarter, and this probably was the case in narrow channels bounded by tidal strands or training walls; but, inasmuch as the tidal gradient was far steeper for the hour and a half before, and the hour and a half after, half ebb than at other periods of the tide, it was likely that this middle portion of the ebb was as effectual as the last quarter in removing the bar, owing to the combined volume and velocity of the current being then at their maximum. In fact, a very large volume of moving water seemed as essential as velocity, and it was to the combination of the two that the removal of great masses of sand or detritus, such as most river bars presented, must be looked for. The Author of the Paper had well remarked that, in the case of Dublin, the absence of training walls along the sides of the navigable channel inside the piers had been beneficial to the harbour, by permitting the surface of the north strand to lower or waste away, whereby the tidal capacity of the harbour was enlarged. But their absence further permitted the progressive straightening and widening as well as deepening of the channel by dredging, according as the revenues of the port allowed; a process which would have been much embarrassed if training walls had been hastily constructed to suit the winding of the river at an early period. Moreover, training walls would probably have caused some silting behind them, and thus have raised, in place of lowering, the adjoining strand level. At the same time it should not be forgotten that the Great South Wall, more than 3 miles in length, did to some extent, as a training wall, constrain the river to follow its own direction, in place of allowing it to wander from side to side of the estuary.

Mr. C. J. Appleby remarked, through the Secretary, that as bars and shoals were only submerged elevations, with corresponding depressions, a process of levelling would perhaps be far more likely to remove them permanently than the slow and costly operation of dredging. Many plans had been suggested for effecting this. The apparatus proposed by M. Bergeron possessed this advantage, that it was capable of being worked at all states of the tide, and even probably in a moderate seaway; but Mr. Appleby feared there would be a loss of useful mechanical effect in forcing a number of small jets of water at a high velocity against an inert mass of water. He thought a more direct application of mechanical power would be found in the apparatus designed some years ago by Mr. J. J. van

Rietschoten, of Rotterdam, and called by the inventor "a propeller dredger." It consisted of an ordinary strong craft (an old gun-boat), a 12-HP. portable engine, and a pair of trussed beams, one on each side of the craft, carrying steel shafts, and suitable bearings for them. These beams were hung from the sides of the craft, so that they could be lifted by tackles and lowered to any depth required. The lower ends of the shafts were fitted with ordinary propellers, about 3 feet 6 inches in diameter, and the upper ends with bevil wheels, to which power was transmitted from the engine fixed in the craft to a cross shaft driven by a belt from the fly wheel. This machinery was tested several times in the river Maas, and in April 1876, when he was present, the craft was steamed into position by its own propellers against the current, the depth of water being then about 13 feet over the shoal, with deep water all round. The propellers were lowered until they nearly reached the top of the shoal, and work was commenced. The engine made ninety-six revolutions, and the propellers about one hundred and fifty-six revolutions per minute, the craft being anchored in such a manner that it could be kept straight to its work, and warped as required to keep on the higher part of the shoal. It soon became apparent that a large quantity of material was set in motion by the revolutions of the propellers, and after about forty minutes' work the engine was stopped and soundings taken. It was then ascertained that the shoal had been lowered about 1 yard in depth for a length of 150 yards, and a width of 8 yards. The craft was next turned round and worked with the stream, the results obtained being practically the same as when working against the stream. The shoal consisted of a coarse, compact sand in water. The machinery was subsequently used, under the supervision of the engineers of the Water Staat, in various kinds of strata, such as fine sand, clay, peat, clay and peat mixed, &c., and the average results were that, including the time necessary for getting the craft into position, about 130 cubic yards of sand were moved per hour, 116 yards of sand mixed with clay, and proportionally lower duties in peat and clay. This appeared to indicate that a great deal might be done in the way of levelling the bottoms of rivers by simple and inexpensive mechanical appliances, which could be worked almost continuously irrespective of variations in the depth of water. The apparatus designed by Mr. van Rietschoten seemed to meet these conditions, and the efficiency of that referred to by M. Bergeron would probably not be materially affected even when working in a moderate seaway.

May 26, 1879.

The President's Conversazione.[1]

By permission of the Committee of Council on Education, Mr. Bateman, the President, on the evening of this day, gave a Conversazione in the Machinery Galleries of the South Kensington Museum. These apartments contain a varied and extensive collection of models of machinery and of naval architecture, of which collection revised catalogues have lately been prepared by the Science and Art Department.

The different Galleries were lighted by electricity. In the first room were displayed four of Higgins's incandescent lights, the electricity being produced by a galvanic battery. In the adjoining vestibule, and in the Gallery in which the reception took place, the Electric Lighting Company exhibited standards fitted with Wilde's automatic carbon-holders, the current being supplied by two Wilde electro-magnetic induction machines, placed in the adjacent porch. In the next vestibule Werdermann lamps were shown, while in the adjacent small ship model room were Serrin lamps, the electric current in this case being produced by two A Gramme machines. These machines, and the lamps connected therewith, were lent by the British Electric Light Company, and were worked by an 8-HP. Otto silent gas engine, contributed by Messrs. Crossley Brothers. The Central Hall received its illumination from three electric lights lent by Messrs. Siemens Brothers, the machines and engine being situated, at a distance of 1,800 feet, in the Albert Hall, whence three leads proceeded to the lights, and a fourth lead was employed to actuate another machine, to illustrate the transmission of power by electrical agency, the amount so transmitted being indicated by a Prony brake. The lighting of the last room was undertaken by the Société Générale d'Electricité, and was effected by Jablochkoff electric candles, the current being supplied by a six-light Gramme dividing machine, worked by a portable steam-engine.

To this collection several objects, specially lent for the occasion, were added, and of these objects a list is subjoined, arranged in alphabetical order of the names of the contributors.

[1] Information in regard to some of the objects specially contributed will be found in "The Engineer" and in "Engineering" for May 30, 1879; in "The Mining Journal" for May 31, 1879; and in other periodicals of about the same date.—Sec. Inst. C.E.

List of Models and Engineering Instruments specially Lent for the President's Conversazione.

Hoffman's Tripod Heads	*S. Abbott, M. Inst. C.E.*
Rails, Joints, and Wedges	*Acaster Patent Rail Joint Co.*
Spring Safety Valves	*Thos. Adams.*
Two Cups of Bessemer Steel	*D. Adamson, M. Inst. C.E.*
Continuous Self-Recording Mercurial Barometer; Instrument for Recording Duration of Sunshine	*Dr. Airy.*
Electric Mining Lamp	*G. G. André, Assoc. M. Inst. C.E.*
Model of Cycloidal Screw Propeller	*Lieut. R. H. Armit, R.N.*
Pair of Jointed Mountain Guns and Equipment; Model of Rendel's method of Mounting Barbette Guns; Model of Weldless Steel Chain for Suspension Bridges	*Sir W. G. Armstrong and Co.*
Hand Ice-Making Machine	*Atlas Engine Co., per G. B. Lloyd, Assoc. Inst. C.E.*
Magneto-Electric Firing Key for Torpedoes; Patent Inductorium; Drawing Instruments and Level; Apparatus for obtaining Spectra in Gases; Barometers; Alarum Thermometer and Clinometer	*Bagot and Apps.*
The "Comet" Pump	*Bartrum and Powell.*
Model and Diagrams of Thirlmere—proposed source for supply of water to Manchester	*J. F. Bateman, Pres. Inst. C.E.*
Steam "Quieting Chambers"	*G. Beck.*
Model of Horizontal Wind-Engine	*Dr. Beckingsale.*
Specimens of Mild Steel Cylinders, crushed to show strength of material, power of yielding without rupture, &c.	*H. Bessemer, M. Inst. C.E.*
Schuckert Machine, and Pyramid and Krupp Electric Lamps	*Capt. W. B. Brain.*
Monocular Microscope	*R. C. Brebner, Stud. Inst. C.E.*
Fire Alarms	*E. B. Bright, Assoc. M. Inst. C.E.*
Two A Gramme Machines, with Serrin Lamps, in ship-model room, and a Gramme Quantity Machine for Werdermann Lamps, in vestibule	*British Electric Light Co., per A. F. Blandy, M. Inst. C.E.*
Three-cylinder Engine for Dynamo-Electric Machine	*P. Brotherhood, M. Inst. C.E.*
Dead-weight Safety Valve; Model of Paper Railway Wheel	*John Brown and Co., Limited.*
Drawing of Cast-Iron Rib for Underground Groyning	*J. H. W. Buck, M. Inst. C.E.*
Paper Testers; Torsional Wire Tester	*W. Carrington, Assoc. M. Inst. C.E.*
Holophotal and Diverging Lenses for Electric Light	*Chance Bros. and Co.*

Model of a Motion for Gunboats of Shallow Draught; Instrument for Measuring $\frac{1}{1000}$ inch	*T. F. Chappé, M. Inst. C.E*
Trouvé's Instruments for the use of the Electric Light in Surgical Operations; New Electric Surgical Lamp	*Dr. W. Harris Coffin.*
Working Model of a Double-Power Floating Dock; New Appliances for the Construction of Piers and Breakwaters	*Clark, Standfield and Co.*
Specimens of Timber preserved by Phenic Acid and by Creosote	*Conner and Co.*
Photographic View of the Proposed Docks at Melbourne; Pictorial Plan of Table Bay Harbour and Dock Works, showing proposed Extensions	*Sir John Coode, M. Inst. C*
Working Models of Electric Lock and Block System for Railways	*Conrad W. Cooke.*
Writing Telegraph; and early Electro-Magnetic Machine	*E. A. Cowper, M. Inst. C.I*
8-HP. and 3½-HP. Otto Silent Gas Engines	*Crossley Bros.*
Dunlop's Pneumatic Marine Engine Governor.	*Cunliffe and Dunlop.*
Model of Floating Swing Bridge	*D. Cunningham, M. Inst.*
Models of Hydraulic and Compound Pumping Engines	*H. Davey, M. Inst. C.E.*
Allen Patent Pneumatic Riveter	*A. Davis, Assoc. Inst. C.E*
Theodolite Level; Miner's Dial, &c.	*J. Davis and Son.*
Model of Quay Walls on Concrete Cylinders, Queen's Dock, Glasgow, and Photographs of Works	*Jas. Deas.*
Models of Cleopatra's Needle (in Bronze), of Method of Transport, and of Erection; Model of a portion of the Staithes Viaduct	*John Dixon, Assoc. M. Ins*
Brown's Combined Steam and Hydraulic Starting Gear for large Marine Engines	*D. Drummond.*
Model of Grooveless Tramway	*C. A. Edge.*
Gramme Six-Light Dividing Machine	*J. Edmundson and Co.*
Models of Steamer of Light Draught, Twin Screw Torpedo Boat, and Gun Launch	*Edwards and Symes.*
Normandy Rock Drill	*E. Edwards.*
Everitt's Cam-Feed Screw Stocks	*R. Edwards, Assoc. M. In*
Wilde Electro-Magnetic Induction Machines and Candles, in reception room and vestibule	*Electric Lighting Co., F. K. Steuart, M. Inst.*
Speed Indicator and Counter	*H. Faija, Assoc. M. Inst.*
Model of Metallic Packing	*E. Faull.*
Model of Watson's Cotton Press; Rousselot's Sugar-Cane Mill	*Fawcett, Preston and H. Shield, M. Inst. C.I*
Model of Invention for Training Great Guns	*G. Fawcus.*
Apparatus for Controlling Pressure of Water in Mains and Pipes	*W. Foulis, M. Inst. C.E.*

Electrical Automatic Apparatus for Indicating the Height of Water in Reservoirs, applied in this case to a Reservoir at Nottingham .	*General Post Office, and H. Rofe, M. Inst. C.E.*
Wood's Wrought-Iron Sleeper and Chair Clip .	*Gilkes, Wilson and Co.*
De Mersanne-Harding's Regulator for the Lontin Electric Light	*W. B. Godfrey, Assoc. M. Inst. C.E.*
Model of Mackison's Tram Rail	*A. Greig, Assoc. M. Inst. C.E.*
Model showing Improved Form for the Stern of Screw Ships	*R. Griffiths.*
Models of Centrifugal Turbines	*J. and H. Gwynne.*
Model of Apparatus for Saving the Breakage of Coal when Falling from Colliery Screens into Wagons.	*T. C. Hair.*
Westinghouse Steam Governor for Ships . .	*J. and E. Hall.*
Models of Ship-Raising Apparatus and of Slide-Valve Motion	*D. Halpin, Assoc. M. Inst. C.E.*
Models of 5-bar Parallel Motions	*Harry Hart.*
Rider's Automatic Expansion Gear	*Hayward, Tyler and Co.*
Working Diagram of Double Rudder Action .	*Capt. Heathorn, R.A.*
Case of Carbons for the Electric Light . . .	*K. Hedges, Assoc. M. Inst. C.E.*
Tramcar Spring Buffer, new Packing . . .	*C. Henwood.*
Improved Means of Hanging and Working Railway Carriage-Window Sashes; Model of Boat-disengaging Apparatus	*Hill and Clark.*
Higgins's Electric Incandescent Lamps, in tea room	*L. C. Hill, Assoc. M. Inst. C.E.*
Models of Iron- and Timber-Roof Truss; Starting Gear for Steam Tramcars; Equilibrium Slide Valve; Cylinder Drain Escape Valve; Steam Reversing Gear; Telemeter Staff applied to a Theodolite	*H. P. Holt, Assoc. M. Inst, C.E.*
Current-Regulator for Electric Light . . .	*E. Hospitalier.*
Prismatic Reflector for Street Lamp . . .	*O. H. Howarth, Assoc. M. Inst. C.E.*
"M" Gramme Machine	*Indiarubber, Gutta Percha, and Telegraph Works Co.*
Photograph of Compound Engine of Inman Steamer	*Institution of Naval Architects.*
Raw Asbestos and Articles Manufactured therefrom	*Italo-English Pure Asbestos Co.*
Waste Water Preventer	*G. Jennings, Jun.*
Hand-Power Rock Drill	*T. R. Jordan.*
Optical Apparatus for Measuring very small Extensions of Bars, in use at the Engineering Laboratory of University College, London . . .	*Prof. Kennedy, M. Inst. CE., and R. H. Willis, Assoc. M. Inst. C.E.*
Permanent Way for Tramways	*J. Kincaid, M. Inst. C.E.*
Photograph of Moist-Air Freezing Machine .	*A. C. Kirk, M. Inst. C.E.*
Hughes' Audiometer	*Krohne and Sesemann.*

Models of "Republica" Gunboat; of "Rose and Shamrock" and "Javary" Paddle Steamers; of "Los Andes" Turret Vessel; of "Han Kwang" Screw Steamer; of Steel Paddle Steamer in course of construction for L. & N. W. Railway Co.; and Bevis's Feathering Propeller	*Laird Bros.*
Railway Wagons with Fenwick's Couplings	*W. Lawford, M. Inst. C.E.*
Models of Fox's Corrugated Boilers and Flue Tubes, &c.	*Leeds Forge Co.*
Models of Patent Tubular Pile and of Coupled Tube Wells	*A. Le Grand and Sutcliffe.*
Instrument for Detecting Inflammable Gas in Mines	*E. H. Liveing.*
Model of Barker's Patent Tramway	*J. H. Lynde, M. Inst. C.E.*
Frictionless Conical-End Logs	*E. Massey.*
Model of Darby's Digger, or Excavating Machine, by Eddington & Co.	*A. Mead, Assoc. M. Inst. C.E.*
Electric Machine	*Baron de Meritens.*
Cement- and Paper-Testing Machines	*V. de Michele, Assoc. M. Inst. C*
Model of 18-Ton Muzzle-Loader Rifled Gun on Colonel Moncrieff's Hydro-pneumatic Carriage	*Col. Moncrieff, M. Inst. C.E.*
Bricks made with Sewage Sludge	*E. Monson, Assoc. M. Inst. C.*
Nordenfeldt's Torpedo Battery Guns	*B. T. Moore, M. Inst. C.E.*
"Show Speed"	*J. M. Napier.*
Eleven Ship-Builders' Half Models of Armour-Clad Ships, including the "Black Prince" and the "Northampton"	*R. Napier and Sons.*
Mallory Screw Propeller	*P. F. Nursey.*
Filter Press for Sewage Drainings; Model of Vosper's Yacht Engine	*J. C. R. Okes, Assoc. M. Inst. C*
Martyn Roberts's Safety Valve for Stationary Boilers	*W. Parsey, Assoc. M. Inst. C.*
Specimens of Bronze Metals	*P. M. Parsons, M. Inst. C.E.*
Models of Engines of "Cristoforo Colombo," and of H.M.S. "Sphinx"	*John Penn and Sons.*
Model of Wheel for Road or Rail	*E. Perrett, Assoc. M. Inst. C.*
Electric Lamps, 3 and 4 Carbon Forms, and "Moderator"	*J. Rapieff.*
Models of Screw Gunboats, Dipper Dredger, Steel Paddle Vessel, Screw Propeller, and of proposed Steel Swing Bridge over the River Thames at the Tower	*G. B. Rennie, M. Inst. C.E.*
Model of Mounting for Telescope at Parsonstown	*Earl of Rosse.*
Model of Gun-Carriage and Gun of H.M.S. "Glatton"	*Royal United Service Institution.*
Model of H.M. Ironclad Corvettes "Belleisle" and "Orion"	*Samuda Bros.*
Model of Morrel's Cinder-Sifting Ash Closets	*Sanitary Appliance Co.*

Models of Baker's Patent Rotary Pressure Blower and Pump; ditto ditto and Gas Exhauster; ditto ditto as applied to the Battery Forge Fires of the Royal Artillery .	*Savile Street Foundry Co., Sheffield.*
Miner's Safety Lamp	*Lt.-Col. J. D. Shakespear, Assoc. Inst. C.E.*
Davies's Injector Worked by Exhaust Steam .	*Sharp, Stewart, and Co., per J. Robinson, M. Inst. C.E.*
Slide Rules.	*F. A. Sheppard, Assoc. M. Inst. C.E.*
Three Electric Lights in central hall; Small Dynamo Machine with Prony Brake at Work; Obach's Galvanometer at work; Samples of Lamps, Carbons, and Projector .	*Siemens Bros.*
Models of Hopper Dredger, and of Elevating Ferry Steamer	*W. Simons and Co.*
Patent Tramway Brake	*B. C. Simpson, Assoc. M. Inst. C.E.*
Model of Wrought-Iron Viaduct.	*H. G. Sketchley, Assoc. M. Inst. C.E.*
Model of Coal and Corn-Shipping Machinery .	*Graham Smith, Assoc. M. Inst. C.E.*
Machine Tools.	*Smith and Coventry.*
Jablochkoff's Electric Candles in machine-model room	*Société Générale d'Electricité.*
Models of Permanent Way for Tramways . .	*I. Spielmann, Stud. Inst. C.E.*
Davy Lamp, fitted with Blue Glass . . .	*A. L. Steavenson.*
Model of Original Design for the Conway Tubular Bridge	*G. R. Stephenson, Past Pres. Inst. C.E.*
Model (*in relief*) of Suez Canal	*Col. Sir J. Stokes, Assoc. Inst. C.E.*
Model of Floating Derrick, and of Diving Bell	*B. B. Stoney, M. Inst. C.E.*
Model of Ship-Ventilating Apparatus . . .	*H. Stott.*
Model of Gimson Duplex Stone or Ore Breaker	*L. Swift, Assoc. M. Inst. C.E.*
Models of Hydraulic Jacks, Stroudley's Ramps, Willans' 3-Cylinder Engine, Steam Pumps, and Weston's Pulley Blocks; Chipping Chisels	*Tangye Bros. and Holman.*
Denham Olphert's Sleeper	*Thomson and Browning, Assocs. Inst. C.E.*
Thomson and Porter's Patent Sewage Valves .	*D. Thomson, M. Inst. C.E.*
Electric Machine	*S. C. Tisley and Co.*
Models of Wolf Rock and of Little Basses Lighthouses; Duboscq Lamp, Holmes' Original Lamp, Holmes' Improved Lamp, and Siemens' Lamp, all for the Electric Light in Lighthouses; Sixth Order Dioptric Lens for Electric Light at Dungeness	*Trinity House, per J. N. Douglass, M. Inst. C.E.*

Cast Iron Treated with Bower's Process to Prevent Oxidation	*W. Tweedie, Assoc. M. Inst. C.E.*
Permanent Way for Tramways, and Models of Warehouse at proposed Tower Bridge	*Hy. Vignoles, M. Inst. C.E.*
Models of Brockelbank's Railway Couplings	*Warner, Walduck and Co.*
Model of Chain Roller Box for Dock Gates	*C. Wawn, M. Inst. C.E.*
Specimens of Strata overlying the Lower Greensand in the Neighbourhood of London	*J. H. Wild, Assoc. M. Inst. C.E.*
Automatic Signal Wire Compensator	*G. W. Willcocks, Assoc. M. Inst. C.E.*
Model of Widmark's Radial Axle Box, and Wilson's Lock-up Arrangement of Klotz' Safety-Valves for Locomotive Engines, &c.	*John C. Wilson.*
Model of Torpedo Boat	*A. F. Yarrow, Assoc. M. Inst. C.E.*

May 27, 1879.

JOHN FREDERIC BATEMAN, F.R.SS.L.&E., President, in the Chair.

THE following Candidates were balloted for and duly elected :— DAVID WILKINSON CAMPBELL, CHARLES SWAINE FAHEY, ALEXANDER BLACKIE WILLIAM KENNEDY, and BENJAMIN SYKES, as Members; GEORGE RUDOLPH BODMER, Stud. Inst. C.E., WILFRID SWANWICK BOULT, FREDERICK LATHAM BROWN, AUGUSTUS JOHN DARLING CAMERON, JAMES CROSBIE, ALFRED JOSEPH GOLDSMITH, JOSEPH RICHARD HAINES, THOMAS HARNETT HARRISSON, STEPHEN HORSLEY, JAMES CADOUX HUDSON, ARTHUR CAMERON HURTZIG, Stud. Inst. C.E., ALEXANDER MACGREGOR, Stud. Inst. C.E., EDMUND ALBERT PARSICK, JOHN JAMES POTTS, ALFRED ELEY PRESTON, Stud. Inst. C.E., THOMAS ANTON SKILLITER, HENRY ROBERT SMITH, ALEXANDER WALLACE, and SAMUEL ROBERT WILKES, B.A., Stud. Inst. C.E., as Associate-Members; ALFRED TEMPLETON HAWKINS, LL.D., GEORGE ERNEST MOBERLY, JAMES MORRIS, and ROBERT WARNER, as Associates.

It was announced that the Council, acting under the provisions of the Bye-Laws, had transferred WALTER RALEIGH BROWNE, M.A., ALBERT BROWN GHEWY, JOSÉ MANUEL FARFAN DE LOS GODOS, RICHARD READER HARRIS, WILLIAM BENJAMIN LEGGATT, EDWARD JOHN THEODORE MANBY, GEORGE WILSON STEVENSON, CHARLES ROBERT WESTERN, and CHARLES HENRY WILKES, from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council as Students of the Institution :—PERCY BAYLIS, CHARLES WALTER CARRINGTON, FRANCIS ALFRED COOPER, PERCIVAL FOWLER, CHARLES JAMES HENRY, GEORGE MONTAGUE MAY, JOHN THOMAS MORKILL, WILLIAM MILNER NELSON, JOHN SEABURY O'DWYER, GEORGE GILBERT WHITE, DE KAY WINANS, and ROBERT WADE WRIGHT.

No. 1,584. "Dock Gates."[1] By Adam Fettiplace Blandy, M. Inst. C.E.

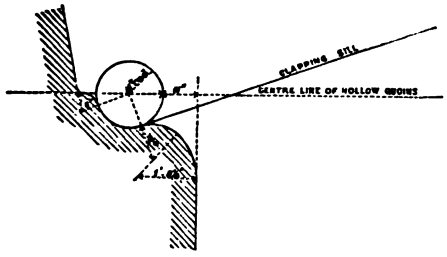
When a dock is situated in connection with a tidal harbour, river, or other waterway, the surface level of which is liable to vary considerably, the passage by which vessels gain access thereto is commonly provided with one pair or more of massive watertight gates, constructed in such a manner that when closed the water in the dock is impounded, and maintained at a fixed level, notwithstanding the fluctuations of the outer waterway. To receive and support the gates, the passage (Plate 2, Figs 1 and 2) is constructed with side walls, and a floor or "sill," the latter having usually the form of an inverted arch. In each side wall, and exactly opposite each other at the position fixed for the gates, recesses are formed the full depth of the walls, and sufficiently large to allow the gates, when open, to stand back in them clear of the fairway of the passage. The area of the floor traversed by the gates whilst opening, termed the "gate platform," is usually made level, and somewhat below the lowest level of the sill, the step from the sill to the platform, called the "clapping sill," having a vertical face, and being shaped horizontally, so as exactly to fit and form a watertight junction with the gates when shut. The so-called "square quoins," forming the ends of the recesses nearest the dock, are solely for the purpose of protecting the gates. They should be of great strength, to withstand the heavy blows to which they are subject; and the salient angles should be rounded off to avoid damage to passing vessels.

The ends of the recesses farthest from the dock are the supports for the gates, and require to be made of suitable form and strength. From their shape they are termed "hollow quoins," and are generally constructed of massive blocks of granite, or other hard stone, backed by counterforts of sufficient size and weight to withstand the thrust of the gates. Various forms of hollow quoins have been devised to suit corresponding gates. The most common is that which presents on plan an outline more or less similar to an ogee moulding. A modification of this form, in use at the Liverpool docks, is shown in Fig. 3, the dimensions being those suitable for gates of 60 feet span. These hollow quoins are set with the axes of the curved faces strictly vertical,

[1] It was announced that the discussion upon this paper would be taken at the first meeting of the next session.

so that they form uniform hollow grooves, extending the full depth of the walls to the level of the gate platform on either side of the passage, the hollow faces of the bottom blocks coinciding with, and forming the terminals of, the clapping sill.

FIG. 3.



Passing over structural details, the gates consist of two exactly similar watertight doors, each somewhat longer than half the width of the passage, and of a depth sufficient to reach from the highest water level to below the level of the sill, against the face of which they shut. The hinge, or "heel-post" end of each gate, is vertical, and rounded so as to correspond with the hollow quoins, the round of the heel-post fitting into the hollow of the hollow quoin, and forming together the hinge about which the gate turns, and the abutment by which it is supported. When moving, the gate is kept in place at the bottom by a pivot and socket connecting the heel-post with the masonry of the platform, and at top by an iron strap passing round the upper extremity of the heel-post, securely anchored into the structure of the side walls.

It has already been stated that each gate is made somewhat longer than half the width of the passage; being similar, they meet on the centre line, and form with each other a more or less obtuse angle, having the convexed side towards the dock. The meeting or "mitre"-post of each gate constitutes or is attached to the vertical end-framing of the gate, and is made so that when the gates are shut the meeting face extends the entire depth, and coincides with the centre line of the passage. The meeting faces of the gates consequently should bear fair and true against each other, and form, when closed, both a watertight joint and mutual abutments.

When the gates are of large size, the weight of a gate is greater than can safely be allowed to depend on the attachments of the heel-post, unless means are adopted to reduce the working weight by the aid of flotation or otherwise; and even then it is advisable

to provide against accidents from defective fastenings, &c. To meet this difficulty a frame, or "truck," provided with a travelling wheel, or "roller," is attached to and supports the gate near the mitre-post end. The roller rests on an iron way laid on the gate platform along the path which it traverses during the process of opening or shutting the gates. Provision is made, by means of wedges, levers, screws, or otherwise, for adjusting the truck to the gate, as the materials wear or circumstances require. As the roller path forms the segment of a circle, of which the centre is the axis of the heel-post, it follows that the outer edge of the roller has to travel a greater distance than the inner edge in the same time. On this account, to avoid sledging, the rollers should be made conical to a corresponding degree, and the axle on which the roller turns should coincide with a straight line radiating from the axis of the heel-post.

Various appliances have been designed for opening and shutting dock gates; but the method usually adopted for large gates is a system of chains, each gate being provided with an opening and a closing chain, attached to the back and front respectively, the attachments being as near the truck and mitre-posts, and as low down, as can conveniently be arranged. The opening chain passes from the back of the gate through a tunnel in the wall of the corresponding recess, up to a powerful crab winch situated at or near the quay level. The closing chain from the front of the gate crosses the water passage, and, traversing a tunnel in the opposite side wall at a convenient distance outside the hollow quoin, passes up to the quay level, where it is connected with a crab winch similar to, but somewhat less powerful, than that used for the opening chain.

The top of a dock gate, when shut, is generally made use of as a footbridge. To effect this the framing of the gate is continued up to coping level, and a gangway of the required width fixed thereon; the hand rails, or guard chains, being so constructed that they can be easily removed out of the way of warps, &c., when a ship is passing.

In all rivers, and most harbours, the water is more or less charged with solid matter, and deposits considerable quantities of silt. To scour the gate platform, and prevent such an accumulation of silt as would interfere with the working of the gates, a series of small openings, on a level with the platform, are often constructed in the walls of the gate recesses. These openings communicate with culverts, which pass under the side walls behind the hollow quoins and discharge into the outer waterway. Cloughs,

or penstocks, are placed in the culverts, so that they can be opened or shut at pleasure; and the culverts, in addition to their scouring properties, afford a means of regulating the level of water in the dock. Sluice openings, provided with paddles, are also frequently constructed in the gates themselves.

STRAINS.

If the surface of the water impounded in the dock is at a higher level than that of the outer waterway, the pressure on the gates due to this difference in level, has to be withstood, and conveyed to the side walls, by the structure of the gates.

The general laws of fluid pressure are so well known, that it is useless to repeat them here.

If a dock gate be imagined to be divided by a series of cross sections into a number of vertical strips, each strip being of unit length, and the full depth of the gate, then the total pressure on any such strip, will be the pressure per unit of length of the gate.

Let p = total pressure on any strip as above, or the pressure per unit of length of gate;
W = weight of water per unit of measure;
D = depth of sill below highest water level; and
d = depth of sill below lowest level of outer water;

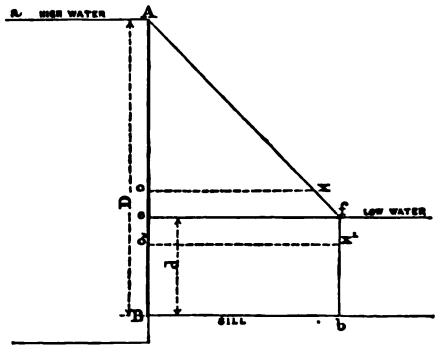
Then $$p = \frac{W}{2}(D^2 - d^2).$$

If the outer water leaves the sill entirely dry, $d = 0$, and $p = \frac{W}{2} D^2$. (Fig. 4).

In treating of the general stresses, it being assumed that the upper and lower portions are similar, a gate will be considered as a horizontal layer, subject to a uniform horizontal pressure per unit of length, of a magnitude $= p = \frac{W}{2}(D^2 - d^2)$. The horizontal stresses thus obtained will be due to the whole water-bearing area of the gate, and these must be distributed throughout the depth, in proportion to the head of water at the various levels. For example: Supposing it is found that at a certain point on the plan of the gate there exists a horizontal stress = F. This force F is not concentrated at a point on the gate, but is the sum of a series of similar horizontal forces, acting throughout the depth from the highest water level to the level of the sill, on the vertical line drawn through the above-mentioned point.

The distribution of F throughout this line can be easily ascertained. (Fig. 4.) Let A B be the vertical line represented by the

FIG. 4.



point on plan through which F acts; A a the highest water level; B b the level of the sill, and e f the lowest level of the outer water. Then A B = D, and e B = d. Make B b = $\frac{2F}{D+d}$; draw b f parallel to A B, and complete the triangle A f e. Then will the figure B A f b be a graphic representation of the vertical distribution of the force F. That is to say, the area of the figure B A f b will represent the whole force F; and if o o^1 be any part of the line A B, the portion of the force F acting between o and o^1 is represented by that portion of the area B A f b which lies between the horizontal lines o x and $o^1 x^1$. Also the intensity at any point o is represented by o x, the portion of the horizontal line through o lying between A B and A f b. Keeping in mind the above-mentioned distribution of forces throughout its depth, a gate will now be considered as a horizontal layer, subject to a uniform horizontal pressure, per unit of length, of a magnitude = $p = \frac{W}{2}(D^2 - d^2)$.

The mutual action of the gates on each other is in practice liable to vary; and three cases must be considered:

1st The gates may be constructed so that, when under pressure, the meeting faces of the mitre-posts bear fair and true against each other, and distribute the mutual reactions uniformly throughout the width of the meeting faces. This is the normal condition of things.

2nd. Foreign substances, such as chips of wood, may intrude;

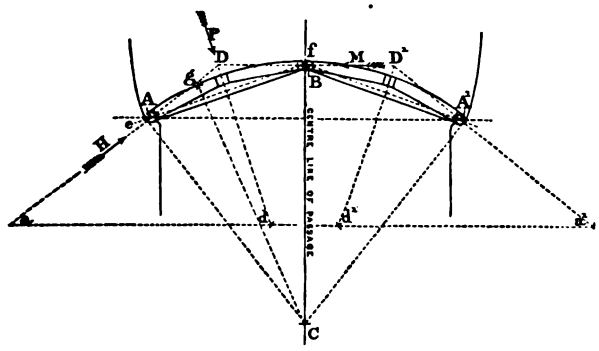
or the gates may wear, and become a little too short, causing them to nip on the dock, or inner edges of the meeting faces.

3rd. The gates may be a little too long, in which case they will nip on the outer edges of the meeting faces.

The first of these is the theoretical condition, and will be assumed in the following investigation of stresses. The effects due to nipping will afterwards be considered.

Let Fig. 5 be a plan of a pair of gates, A and A^1 being the centres of the heel-posts, B the centre of meeting faces of mitre-posts. Considering the left-hand gate A B, the primary forces

FIG. 5.



NOTE.—The supplementary triangles D a d, $D^1 a^1 d^1$ are merely for the purpose of checking the work. D d is made equal to e f, and $a a^1$ drawn parallel to $A A^1$. Then should D a = C e; and d a = C f.

acting on this are: P = water pressure; M = the reaction of the other gate on the mitre-post; and H = the reaction of the hollow quoins on the heel-post.

The water pressure, P, acts throughout the extent of, and in all cases normal to, the exposed surface of the back of the gate. If the pressure per unit of length = $p = \frac{W}{2}(D^2 - d^2)$, the magnitude of the resultant force P, equivalent to the whole of this pressure, is proportional to, and may be represented by, the length of the horizontal straight line e f, joining the extremities of the water-bearing surface, that is, $P = p \times e f$. The direction is that of a horizontal straight line D d, perpendicular to, and bisecting, the first-mentioned line e f.

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[1] $p = \frac{W}{2}(D^2 - d^2)$

In the case of the reaction of the other gate on the mitre-post M, assuming that the gates meet on the centre line of the passage, and that this is perpendicular to a straight line, A A^1, drawn through the centres of the heel-posts, the mutual reaction of the mitre-posts on each other will be perpendicular to the centre line of the passage, and parallel to A A^1. No other direction will admit of equilibrium. It has already been assumed that the mitre-posts meet, so that the mutual reactions are uniformly distributed throughout the width of the meeting faces; consequently the direction of the resultant force M, representing the reaction of the other gate, will be that of the horizontal straight line B D, which bisects the meeting faces in B, is parallel to A A^1, and cuts the line D d at the point D.

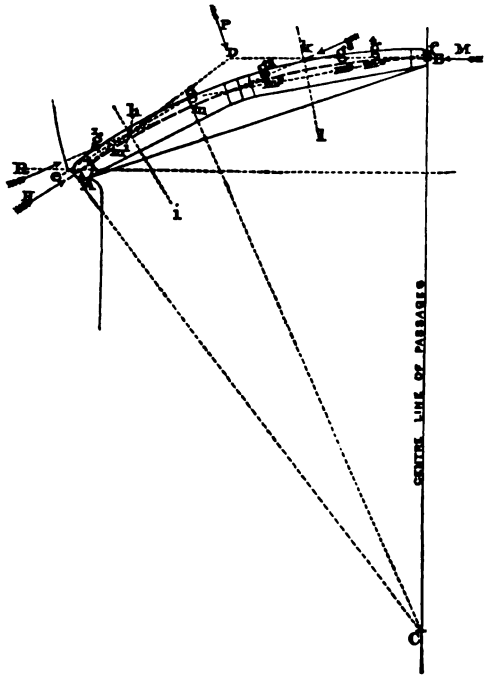
The reaction of the hollow quoins on the heel-post H obviously acts through the centre of the heel-post, and from the conditions of equilibrium its line of direction must pass through the point of intersection of the other two forces. The line of direction of this force H will therefore be represented by the line A D. If from point e, the extremity of the water-bearing surface at the heel-post, a line e C be drawn perpendicular to A D, and cutting the centre line of the passage in C, then will the length of the line C e be proportional to the magnitude of the reaction H, and the length of the line C f will be proportional to the magnitude of the reaction M. That is to say, $H = p \times C e$, and $M = p \times C f$. Further, if g be any point on the back of the gate, the length of the line C g will be proportional to the magnitude of the resultant force R acting on any vertical section passing through g. That is to say, $R = p \times C g$, and the direction of such resultant will be perpendicular to C g.

To find the position of the resultant force R, acting on any vertical section passing through g: let Fig 6 be an enlarged plan of the gate, A D and B D the lines of direction of H and M, C the point on the centre line of the passage found as before, and g any point on the back of the gate. Join C g, g e, and g f; draw h i perpendicular to and bisecting g e, and cutting A D in h; also draw k l perpendicular to and bisecting g f, and cutting B D in k; join h k, cutting C g in m. Then will h k be perpendicular to the line C g, and will be the direction of R, the resultant of all the forces acting on the heel-post side of any vertical section passing through g. It has already been said that the magnitude of R is proportional[1] to the length of the line C g. The resultant of the

[1] $R = p \times C g$; $p = \frac{W}{2}(D^2 - d^2)$.

forces acting on the mitre-post side of the section is equal in magnitude, but opposite in direction.

FIG. 6.



By taking a sufficient number of points, g g^1 g^2 g^3, &c., and proceeding as above, a number of points, m m^1 m^2 m^3, &c., can be obtained, in which the respective resultants cut the lines C g C g^1 C g^2 C g^3, &c. Then joining the points A m m^1 m^2 m^3 B, a line will be obtained passing through the points A and B, which may be termed the line of position of resultants. The form of this line will depend on the shape of the gate; and it must be borne in mind that the line of direction of the resultant force acting on any particular section is not necessarily tangential to the line A m m^1 m^2 m^3 B, but is always perpendicular to the line radiating from C. If the backs of both gates when shut form one continuous arc of a circle, as in Fig. 7, the line A m m^1 m^2 m^3 B will also be the arc of a circle, having its centre at C; nor will there be any appreciable difference if the angles of the mitre-posts are chamfered off so as

to destroy the continuity of the back, as in Fig 8, provided B is always at the centre of the meeting faces. When the "rise" of the gate, that is, the versed sine of the arc A B A^1, does not exceed one-fifth of the chord A A^1, then, for all forms of gate lying between

Fig. 7.

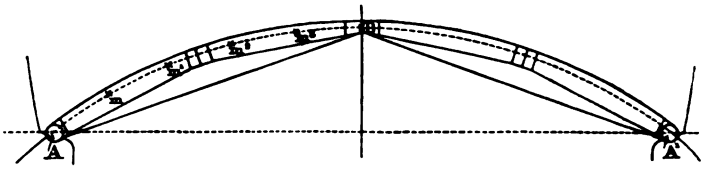


Fig. 8.

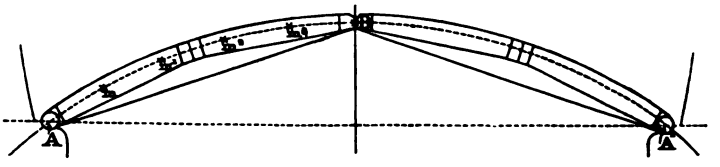


Fig. 9.

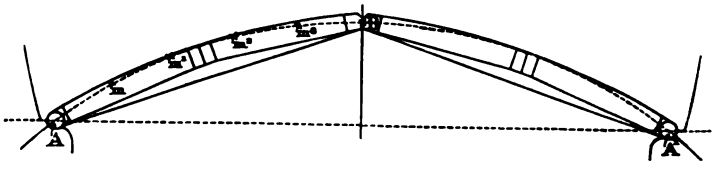
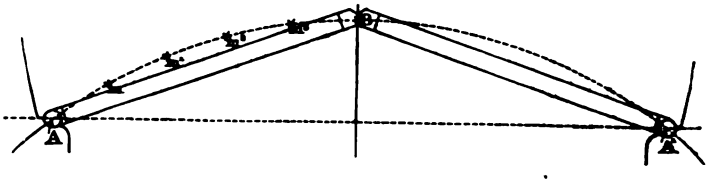


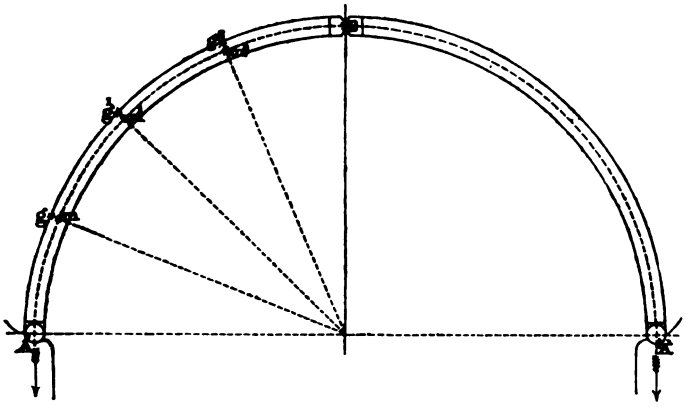
Fig. 10.



the straight back and that of the continuous arc, the line A m m^1 m^2 B will approximate so closely to the arc A B A^1 that the latter may be used as the line of position of resultants, the error being so small that it may safely be neglected. Figs. 7, 8, 9, and 10 show various forms of gate, the "rise," however, being the same in all, viz., about one-sixth of the span. In each case the line of position of resultants is marked by a dotted line, and may be considered as the arc of a circle.

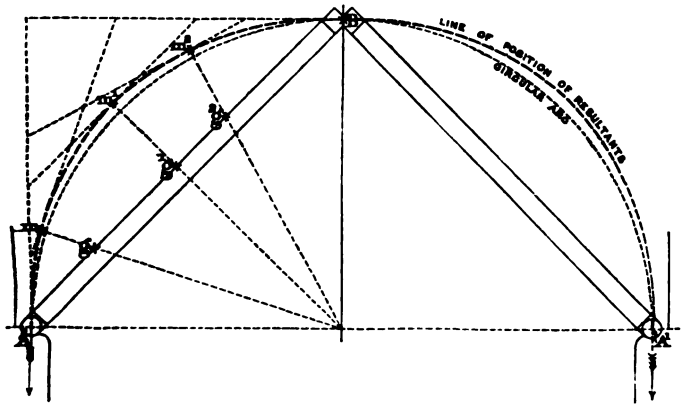
If, however, the "rise" is large in proportion to the span, the line A m m^1 m^2 m^3 B only corresponds with the arc A B A^1 when the back of the gate is of the form of the continuous arc, as in Fig. 11. With a rise = half the span, and a straight-backed

FIG. 11.



gate, the difference is considerable at the centre of the gate, as will be seen in Fig. 12, in which the thick dotted line represents

FIG. 12.

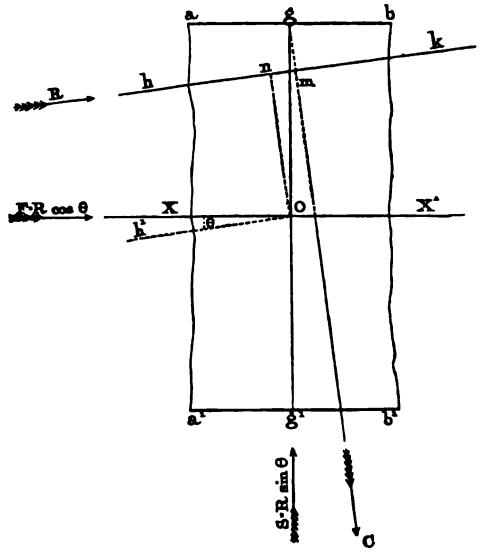


the line A m m^1 m^2 B, and the fine dotted line the arc A B A^1. In a case such as this it will be necessary to find separately, in the manner before indicated, as many of the points m m^1 m^2 m^3, &c., as may be required. The instances in which the arc A B A^1 coincides with, or approximates to, the line of position of resultants, have

been dwelt upon, as they are those which commonly occur in practice. In designing a pair of gates, having fixed on the "rise," it will be found convenient to draw the arc A B A^1, and to use it as the line of position of resultants whilst arranging the general dimensions, and then, if necessary, to find the actual position for any particular section by the method before described. Supposing the gate to be divided into an infinite number of vertical sections taken on lines radiating from point C, the line formed by the centres of resistance of all the sections may be termed the axis of the gate. Then, if the line A m m^1 m^2 m^3 B coincides with this axial line, the gate will be subject to compressive stress only; but, if A m m^1 m^2 B differs therefrom, there will be a bending moment in addition to the compressive stress, and also in some instances a shearing force. A glance at Figs. 7, 8, 9, and 10 will show that, whereas the gates in Figs 7 and 8 may be subject to compressive stress only, those in Figs. 9 and 10 must be subject to a bending moment at the centre.

Let a b b^1 a^1, Fig. 13, be an enlarged plan of part of the gate at g,

FIG. 13.



and C m g the direction of a line from C passing through g, R the resultant of the forces acting on the left-hand side of g, h k the line of direction of R, g O g^1 a line through g normal to the axis and cutting the same in O, [this line g O g^1 represents a vertical section

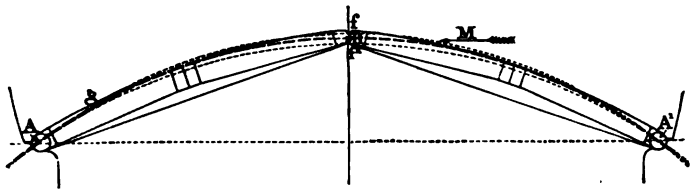
of gate], and X O X^1 a line tangent to the axis at O. Draw h^1 O parallel to h k, and n O perpendicular to h k; then the effect of the forces acting on the left-hand side of the line g O g^1 is equivalent to that of a force[1] = R acting at O in the direction h^1 O, plus a bending moment = R × n O. Resolving in the direction of X O X^1, and perpendicular thereto, if the angle h^1 O X = Θ, then the forces are—

$$S = R \sin \Theta \text{ in the direction } g^1 O g,$$
$$F = R \cos \Theta \quad \text{,,} \quad X O X^1,$$

and m^1 = R × n O = bending moment.

"Nipping" must now be considered. However truly a pair of gates may apparently be fitted, it will be impossible for the engineer to say with absolute certainty that the meeting faces of the mitre-posts bear on each other at any particular point, or in any specified proportion of their surface; and he must provide for the accident of "nipping," which may throw the line of pressure either to the extreme inner or the extreme outer edge of the meeting face. If, on the supposition that M acts through the centre of the meeting faces of the mitre-posts B, the line of position of the resultants corresponding thereto A B A^1 be drawn (Fig. 14); and also, on the supposition that M may act through f or f^1 instead of B, the corresponding

Fig. 14.



lines A f A^1 and A f^1 A^1 be drawn, then the effect of "nipping" will be to increase or diminish the normal bending moment at any section by a quantity very nearly equal to R multiplied by the perpendicular distance at that section between the normal line A B A^1 and the line corresponding to the edge at which nipping takes place. For instance, if a b b^1 a^1 be an enlarged plan of part of the gate at g (Fig. 15), it has already been shown that the normal stresses on the left-hand side of the section g g^1 are—

$$S = R \sin \Theta \text{ in the direction } {}^1g O g = \text{shearing force},$$
$$F = R \cos \Theta \quad \text{,,} \quad X O X^1$$

and m^1 = R × n O = bending moment.

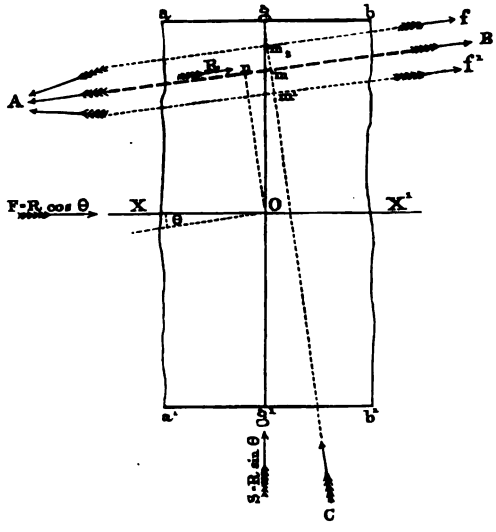
---

[1] R = p × C g.

Now, if the gates nip at f the position of R will be transferred from the line A B to the line A f, and the bending moment will be increased by a quantity very nearly equal to $R \times m m_2$. If the effective bending moment $= M^1$, then $M^1 = R \times (n O + m m_2)$ very nearly; similarly if the the gates nip at f^1, $M^1 = R \times (n O - m m^1)$ very nearly; and the greatest of these must be taken when calculating the maximum stresses. To the above equations the qualification "very nearly" has been added, because they are not mathematically exact.

When the gates nip at f the position of C is slightly altered, say to c, and c g is consequently slightly less than C g, so that the

FIG. 15.



new value of the resultant is somewhat less than R; consequently the bending moment does not increase by a quantity $= R \times m m_2$, but by a quantity somewhat less than that. On the other hand, if the gates nip at f^1 the value of R will be increased, and the bending moment will diminish by a quantity somewhat less than $R \times m m^1$.

If, however, R be considered to remain the same, the error will be very small, and, such as it is, will, in case of nipping at f, be on the right side, as it will tend to show the stresses somewhat greater than they really are.

Assuming, therefore, that R remains the same, and since $m_2 = m\ m^1$, the effective forces acting on the section under consideration may be taken as—

$$M^t = R \times (n\ O \pm m\ m^1),$$
$$F = R \cos \Theta \text{ in the direction } X\ O\ X^1,$$
$$S = R \sin \Theta \quad ,, \quad g^1\ O\ g,$$

S represents the shearing force through g normal to the axis.

The effects due to F and the bending moment M^t will depend on the construction of the gate.

$$\text{Since } R = p \times C\ g \qquad \text{(page 160)}$$
$$\text{and} \quad p = \frac{W}{2}(D^2 - d^2) \qquad \text{(page 157)}$$

Therefore—

$$M^t = \frac{W}{2}(D^2 - d^2) \times C\ g \times (n\ O \pm m\ m^1),$$
$$F = \frac{W}{2}(D^2 - d^2) \times C\ g \times \cos \Theta,$$
$$S = \frac{W}{2}(D^2 - d^2) \times C\ g \times \sin \Theta.$$

It now becomes necessary to examine the effect of direct compressive stress combined with bending moment, when applied to various forms of structure, such as are common in dock gates.

1st. The effect on rectangular wooden beams.

2nd. When the gate is built in divisions corresponding to the voussoirs of an arch, and either depends entirely on the arch form for its power of resistance (in which case no tensile stress can be permitted), or else is assisted by the supplementary connecting pieces, necessary with this form of gate, to combine the whole into one stable structure, capable of being moved and strained in various directions without dislocation. The wooden gates in use throughout the Liverpool docks are of this type.

3rd. The effect on a solid rectangular wooden beam supplemented by wrought-iron truss rods.

4th. On a wrought-iron girder composed of flanges connected by a centre web.

As regards wooden beams. To arrive at an absolute analysis of stresses would require an accurate knowledge of the changes of form caused by the application of forces of compression and tension, more particularly as to the ratio of compressibility to extensibility;

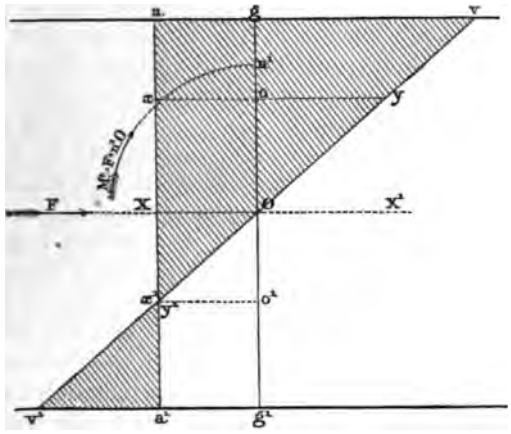
and, unfortunately, on this point there is but little reliable evidence forthcoming. Many experiments have been made on the direct compressive and tensile strengths of different woods, but, from various causes, the results obtained are, at the best, but indications of the relative strengths, and in using such results the practical man finds it necessary to give large factors of safety before applying them to his work. Still more numerous experiments have been made on the strength of beams subject to a transverse strain, and these, though very valuable when bending moments only are concerned, assist but little if they are combined with other stresses. Some few attempts have also been made to determine by experiment the direct ratio of compressibility to extensibility, but these are limited, and scarcely reliable.

Mr. P. Barlow, in his work "On Materials and on Construction," mentions, among others, some experiments on rectangular fir beams subjected to transverse strain, and finds the neutral axis of such beams to be $\frac{5}{8}$ths of the depth from the compressed side, and $\frac{3}{8}$ths from the extended side. This would give the ratio of compressibility to extensibility of the fir used = $\frac{2}{3}^{5}$ths; the terms compressibility and extensibility being employed to express the diminution or increase of length caused by a direct stress of unit force per unit of area of section, of compression, or tension, respectively. Mr. Barlow, however, observes that Mr. Hodgkinson finds the ratio of the distances of the neutral axis from the compressed and extended sides as 4 : 4; that is to say, he finds the neutral axis in the centre of the beam, which would make the compressibility equal to the extensibility, so that there is considerable difference of opinion on the subject. There can be little doubt but that the ratio varies in different woods, and even in different specimens of the same wood. It is, moreover, probable, that it varies with the magnitude of the stresses, though when within the limits of elasticity, it is hardly possible that the latter cause can produce any appreciable difference. The practical conclusion is, that there are no data from which the ratio of extensibility to compressibility can be accurately determined; and any attempt at an absolute analysis of stresses must therefore be abandoned, until such time as experiment or theory provide the missing link. For practical purposes, however, a sufficiently close approximation can probably be obtained, by assuming that in the fibres of a wooden beam the extensibility is equal to the compressibility, and that the stresses due to a bending moment increase in direct proportion to their distance from the neutral axis; the neutral axis in this case meaning the point or line at which the compression due to a

bending moment ends and tension begins. On these assumptions the following investigations are based.

1st. The effect on a rectangular wooden beam.—The forces to be considered are (see page 167) F = direct compressive force acting along the axis, and M^1 = bending moment. Let Fig. 16 be a plan of

FIG. 16.



part of the beam at g, and let X O X^1 be the axis of the beam; g O g^1, the line perpendicular to X O X^1, representing the section under consideration, and cutting the lines representing the sides of the beam at g and g^1; so that g g^1 = breadth of beam at section. Let

A = the sectional area of the beam, $D^1 = \frac{A}{g\,g^1}$ = depth of the beam.

And since the beam is rectangular, O g = O g^1. Make $X\,O = \frac{F}{A}$; and draw a X a^1 parallel to g O g^1, a g v and v^1 a^1 g^1 parallel to each other and to X O X^1; then will the parallelogram a g^1 be a graphic representation of the compressive stress due to the force F. That is to say, the area of the parallelogram a g^1 is proportional to the whole force F; and the intensity of stress due to F per unit of area of the section, at any point o, is represented by x o, the portion of the line through o parallel to X O X^1 lying between a a^1 and g g^1.

If M^1 tends to turn round O from left to right, let v be a point on the line a g v to the right of g, such that length $g\,v = M^1 \times \frac{6}{A \times g\,g^1}$. Through v and O draw the straight line v O v^1, cutting v^1 a^1 g^1 in v^1; then will the triangle g O v represent the compression,

and g^1 O v^1 the tension, caused by the bending moment M^t. The intensity of stress due to M^t at any point o, per unit of area of the section, will be represented by o y, the portion of the line through o parallel to X O X^1, lying between g g^1 and v v^1, such stress being compression or tension according as o y lies to the right or left of g g^1. The total intensity of stress at any point o, on the line g g^1, is obviously equal to the algebraic sum of the intensities due to force F and the bending moment M^t respectively, if compressive stresses are considered as positive, and tensile stresses as negative quantities. Graphically, the total intensity of stress at any point o is represented by the line x y, and will be compression or tension according as y lies to the right or left of x. It will be noticed that of the triangle g^1 O v^1, representing tension due to M^t, a portion, g^1 O y^1 a^1, overlies part of the parallelogram a g^1, which represents compression due to force F. The stresses of compression and tension represented by the area g^1 O y^1 a^1 therefore neutralise each other; and if v^1 g^1 exceed a^1 g^1, then, for a point o^1 corresponding to y^1, $o^1 x^1 = -o^1 y^1$, and therefore $o^1 x^1 + o^1 y^1$ = nil. So that at point o^1 there is neither tension nor compression, and the line $o^1 x^1$ will be the neutral axis of the beam, which will tend to bend round o^1. If point v^1 coincides with a^1, o^1 will coincide with g^1, and the side of the beam at g^1 becomes the neutral axis; at the same time g v becomes equal to g a, and the side of the beam at g is subject to a total compressive stress the intensity of which is equal to twice O X, that is, to a stress per unit of area equal to $\frac{2F}{A}$. This is the case when $M^t = F \times \frac{g\,g^1}{6}$; or, in other words, it is the case of a beam subjected to a compressive stress, the resultant of which acts parallel to the axis, and within the beam, at a distance from the side equal to $\frac{1}{3}$ of the breadth of the beam.

If $M^t = F \times g\,g^1 \times b$, then $g\,v = \frac{F}{A} \times 6\,b$, and the total intensity of stress at g is equal to $\frac{F}{A}(1 + 6\,b)$, and the intensity of stress at g^1 is $\frac{F}{A}(1 - 6\,b)$.

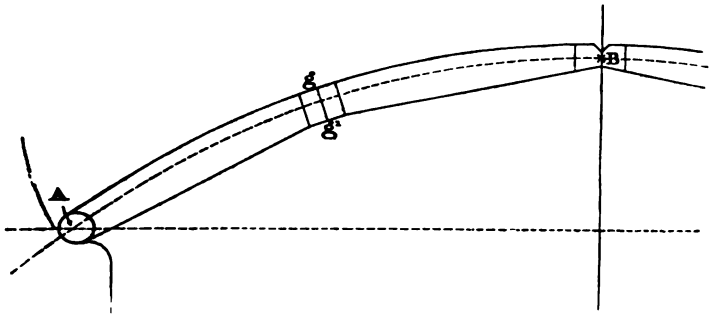
For example: If a beam is subject to the action of forces the resultant of which acts parallel to the axis but through g at one side of the beam, so that $M^t = F \times \frac{1}{2}\,g\,g^1$, then $b = \frac{1}{2}$, and the intensity of the stress at g is equal to $\frac{F}{A}(1 + 6\,b) = \frac{4F}{A}$. That is, the maximum intensity is four times as great as if F had acted

along the axis. The intensity at g^1 is $\frac{F}{A}(1 - 6b) = \frac{F}{A} \times -2$; the minus sign showing that the stress at g^1 is tension, the maximum intensity of which is equal $\frac{2F}{A}$.

2nd. The effect on a gate which is built in divisions corresponding to the voussoirs of an arch.

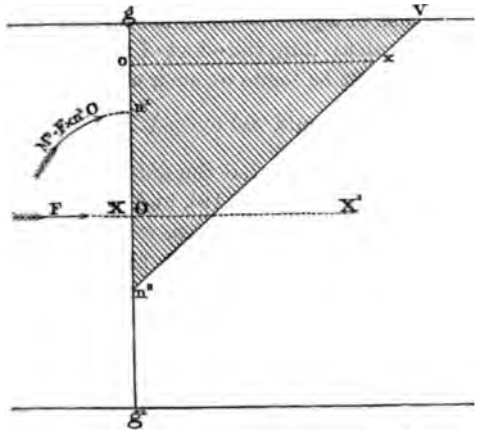
Case 2, A.—The gate depends entirely on the arch form for its stability, and no tensile stress can be permitted (Fig. 17).

FIG. 17.



The joint between two divisions, or voussoirs, is obviously the critical point requiring attention. Assuming that the plane of the

FIG. 18.



joint is perpendicular to the axis of the gate: in Fig. 18, let g O g^1 be a plan of the joint under consideration perpendicular to and cutting

the axis at O, and having g and g^1 respectively at the inner and outer extremities of the joint; $X\,O\,X^1$ the tangent to the axis at O; F = force acting along $X\,O\,X^1$; M^t = bending moment round O; and D^1 = vertical depth of the voussoir. If M^t does not exceed $F \times \frac{g\,g^1}{6}$, the same method of investigation may be used as in Case 1.

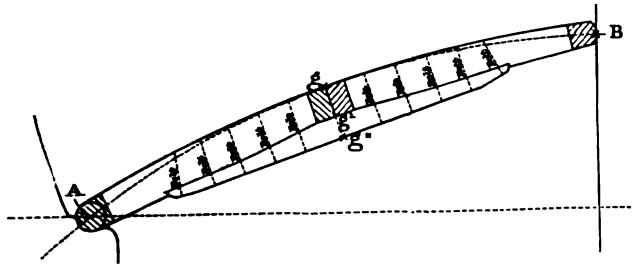
If M^t exceeds $F \times \frac{g\,g^1}{6}$, but is less than $F \times \frac{g\,g^1}{2}$, and acts[1] as before from left to right, draw g v parallel to $X\,O\,X^1$; on the line $g\,O\,g^1$ take a point n^1, such that $F \times n^1\,O = M^t$; let n^{II} be another point on the same line such that $g\,n^{II} = 3\,g\,n^1$, make $g\,v = \frac{2\,F}{g\,n^{II} \times D^1}$, and join $v\,n^{II}$; then will the triangle $g\,v\,n^{II}$ be a graphic representation of the compressive stress on the joint. That is to say, if A = area of triangle $g\,v\,n^{II}$, then $A \times D^1 = F$, and the intensity of stress per unit of area of joint, at any point o, is represented by o x, the portion of the line through o, parallel to $X\,O\,X^1$, lying between $v\,n^{II}$ and $g\,g^1$. If the line $g\,O\,g^1$ represents merely a simple butt joint, it is obvious that no tension can exist at any point of the same. Consequently $n^1\,O$ must not exceed $\frac{g\,g^1}{2}$, otherwise the gate will fail under the smallest pressure. It is also evident that the same will occur when $n^1\,O = \frac{g\,g^1}{2}$, for then n^1 and n^{II} will coincide with g, and the whole pressure will be on a theoretical line at the extreme edge of the gate, and the stress at that edge will be infinite. Therefore, in the case of a gate built in the form of voussoirs, when, for the purposes of calculation, the effect of the fastenings, if any, is neglected, the gate must be made of such a form that M^t shall be less than $F \times \frac{g\,g^1}{2}$; M^t should not exceed $F \times \frac{g\,g^1}{6}$.

Case 2, B.—Now, supposing that the gate is built in divisions as before, but of less curvature (Fig. 19), and requires the assistance of the supplementary connecting pieces, which must be taken into account when computing the strength: here, as in Case 2, A, the joint $g\,g^1$ between two divisions may be regarded as the critical point to be considered, and it may be assumed that the plane of the joint is made perpendicular to the axis of the gate. Looking at the general features of this gate, the first impression is to regard it as a form of "bowstring" girder; but farther consideration will show that this cannot be, as there is nothing to transmit the

[1] See Appendix B.

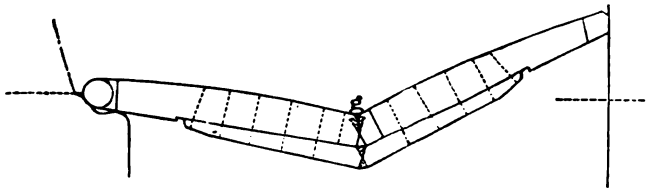
longitudinal stresses from the "bow" to the "string," the transverse bolts being obviously insufficient for that purpose. When,

FIG. 19.



however, the action of a bending moment causes the gate to deflect, the result will be somewhat as shown in an exaggerated form in Fig. 20. The transverse bolts, though allowing the voussoirs and connecting pieces to slide on each other longitudinally, will maintain them laterally in their relative positions to each other;

FIG. 20.[1]



It is assumed that the gate is built of rectangular timbers.

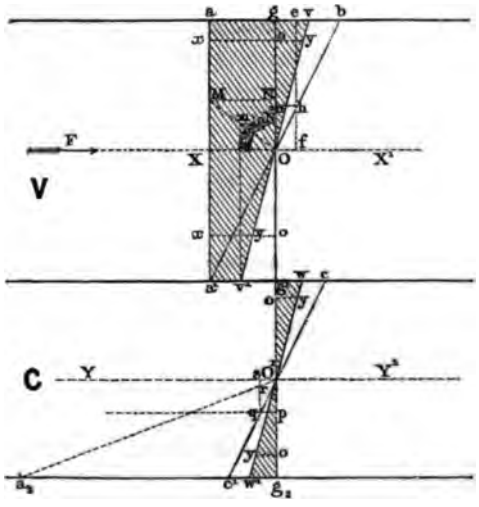
consequently they will bend through similar angles, and the total moment of resistance will be the sum of the moment of resistance due to the voussoir plus the moment of resistance due to the connecting pieces. The direct compressive force F will be entirely on the voussoir, and may be taken as acting along the centre line of the same, the value of the bending moment M^1 being ascertained accordingly.

Let Fig. 21 be an enlarged plan of part of the gate at the joint under consideration, V being the voussoir, and C being the connecting piece: g O g^1 a line representing the joint perpendicular to, and cutting the centre line of, the voussoir at O, and having g and g^1 respectively at the outer and inner edges of the joint; g^1 O^1 g_2 a

[1] The compression and extension would of course, be distributed throughout the gate in due proportion. For the sake of simplicity they are here shown at the centre joint only, the remainder of the gate being, in the sketch, assumed to be rigid.

continuation of the above line, cutting the centre line of the connecting piece at O^1, and the outer edge of the same at g_2; $X\,O\,X^1$ the tangent at O to the centre line of the voussoir; $Y\,O^1\,Y^1$ a line through O^1 parallel to $X\,O\,X^1$. Let A = sectional area of the voussoir; a = sectional area of the connecting pieces; F = force acting along $X\,O\,X^1$; M^1 = bending moment round O; m_v^1 = moment of resistance due to the voussoir; and m_c^1 = moment of resistance due to the connecting pieces. Therefore $M^1 = m_v^1 + m_c^1$. Draw a g b, $a^1\,g^1$ c, and $a_2\,g_2$, parallel to $X\,O\,X^1$; make $O\,X = \frac{F}{A}$, and $g_2\,a_2 = \frac{F}{a}$; draw a X a^1 parallel to g O g^1, and $a_2\,O^1$ a straight line joining O^1 and a_2. Then, as before, the parallelogram a g^1 will be a graphic representation of the compressive stress due to F, the intensity of which per unit of area of the joint, at any point o, is represented by x o, the portion of the line through o, parallel to $X\,O\,X^1$, lying between a a^1 and g g^1.

FIG. 21.



If M^1 tends to turn round O, from left to right as before, through a^1 and O draw the straight line b O a^1, cutting a g in b; make $a\,e = \frac{1}{3}\,a\,b$, and draw e f parallel to g O, cutting $a^1\,b$ in h, and $X\,O\,X^1$ in f. Draw n h parallel to $X\,O\,X^1$, cutting g O in n. [1]Then will the triangles g O b and g^1 O a^1 represent, respectively, the compressive and tensile stresses due to a moment of resistance in the

[1] $a\,a^1 = 3\,g\,n$. See Appendix B.

voussoir, equal to $F \times n\,O = F \times \frac{g\,g^1}{6}$. But before a moment of resistance = $F \times n\,O$ can be produced, the voussoirs must deflect through a certain angle, and consequently the connecting pieces must also deflect through a similar angle, giving rise to a further moment of resistance due to the connecting piece. Now, since the angles of deflection are equal, the triangles representing the stresses of tension and compression due to this additional moment can be formed by drawing through O^1 the line $c\,O^1\,c^1$, parallel to $b\,O\,a^1$. Then the triangles $g^1\,O^1\,c$ and $g_2\,O^1\,c^1$ represent the stresses due to a moment of resistance in the connecting piece, corresponding to the moment of resistance in the voussoir (= $F \times n\,O$).

The value of the moment represented by the triangles $g^1\,O^1\,c$ and $g_2\,O^1\,c^1$ is equal to $\frac{g_2\,c^1}{2} \times \frac{a}{2} \times \frac{2}{3} g^1\,g_2 = g_2\,c^1 \times a \times \frac{g^1\,g_2}{6}$. Make $O^1\,p = \frac{g^1\,g_2}{6}$; draw $p\,q$ parallel to $Y\,O^1\,Y^1$, cutting $c\,c^1$ in q; and $q\,r\,s$ parallel to $O^1\,g_2$, cutting $a_2\,O^1$ in r, and $Y\,O^1\,Y^1$ in s; then $q\,s = O^1\,p = \frac{g^1\,g_2}{6}$, and[1] the required moment of resistance = $g_2\,c^1 \times a \times qs = g_2\,a_2 \times a \times r\,s = F \times r\,s$. Therefore the total moment of resistance corresponding to the lines $b\,a^1$ and $c\,c^1 = F \times n\,O + F \times r\,s$. If now $n\,N$ be made = $r\,s$, $N\,O = n\,O + r\,s$, and the total moment is = $F \times N\,O$, then $F \times N\,O$ is the bending moment corresponding to the intensities marked by the lines $b\,a^1$ and $c\,c^1$.

The lines marking the intensities corresponding to any bending moment less than $F \times N\,O$ can be easily deduced from this. Through N draw $N\,M$, parallel to $X\,O\,X^1$, cutting $a\,a^1$ in M, and join $O\,M$; then for any bending moment = $F \times N_1\,O$ (less than $F \times N\,O$), draw $N_1\,m$, parallel to $X\,O\,X^1$, cutting $O\,M$ in m; $m\,v^1$ parallel to $g\,O\,g^1$, cutting $a^1\,g^1$ in v^1.

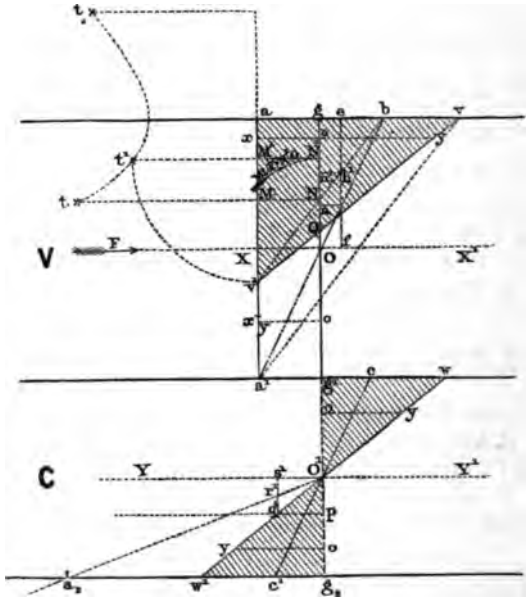
Through O draw $v\,O\,v^1$, cutting $a\,b$ in v, and through O^1 draw $w\,O^1\,w^1$ parallel to $v\,v^1$, cutting $g^1\,c$ and $g_2\,c^1$ in w and w^1 respectively. Then will the triangles $g\,O\,v$ and $g^1\,O\,v^1$ represent the stresses on the voussoir due to the bending moment = $F \times N_1\,O$, and the stresses on the connecting pieces will be represented by the triangles $g^1\,O^1\,w$ and $g_2\,O^1\,w^1$. That is, if o be any point on the line $g\,g_2$, the intensity of stress at o due to M^1 (= $F \times N_1O$) is represented by $o\,y$, the portion of the line through o, parallel to $X\,O\,X^1$, lying between $g\,g_2$ and $v\,v^1$, or $w\,w^1$, as the case may be, such stress being compression or tension according as y lies to the

[1] $g_2\,a_2 = \frac{F}{a}$.

right or left of o. If o lies between g and g^1, the total intensity at o is represented by x y as before, and in this case must always represent compression.

If M^t exceeds $F \times N O$ another method must be adopted. In Fig. 22, with the same notation as before: Suppose that for a certain value of M^t the moment of resistance due to the voussoir $= m_v^t = F \times n^1 0$; draw $n^1 h^1$ parallel to $X O X^1$, cutting e f in h^1; and [1] draw $b h^1 v^1$, cutting a a^1 in v^1; parallel to v^1 b, draw $a^1 v$, cutting a b in v; and draw the line v Q v^1, cutting g g^1 in Q; then will the triangle g Q v represent the compression, and the figure g^1 Q v^1 a^1 the tension, corresponding to $m_v^t = F \times n^1 O$. Through O^1 draw w O^1 w^1 parallel to v Q v^1, cutting a^1 c in w, and a_2 g_2 in w^1; then will the triangles g^1 O^1 w and g_2 O^1 w^1 represent the

FIG. 22.



compressive and tensile stresses due to m_c^t, the moment of resistance in the connecting piece corresponding to the moment of resistance in the voussoir $= m_v^t = F \times n^1 O$. Proceeding in the same manner as before: $m_c^t = F \times r^1 s^1$. The total moment of resistance $M^t = m_v^t + m_c^t = F \times n^1 O + F \times r^1 s^1 = F \times (n^1 O + r^1 s^1)$.

If now $n^1 N^1$ be made $= r^1 s^1$, then $M^t = F \times N^1 O$.

[1] $a v^1 = 3 g n^1$. See Appendix B.

$F \times N^1 O$ is therefore the bending moment corresponding to the intensities marked by the lines $v\,v^1$ and $w\,w^1$ (Fig. 22).

Through N^1 draw $N^1 M^1 t^1$, parallel to $X O X^1$, and mark off the point t^1 so that $M^1 t^1 = M^1 v^1$. By taking various values of $n^1 O$ (greater than $n O$), and proceeding in the above manner, it is easy to trace the curve $t t_2$, so that for any value of $N^1 O$, $M^1 t^1 = M^1 v^1$. Having drawn the curve $t t_2$, then for any value of $M^1 = F \times N^1 O$ (Fig. 22); draw $N^1 M^1 t^1$ parallel to $X O X^1$, cutting $a a^1$ in M^1 and $t t_2$ in t^1; on the line $a a^1$ make $M^1 v^1 = M^1 t^1$, and draw $a^1 v$ parallel to $v^1 b$, cutting $a b$ in v; draw the straight line $v v^1$, cutting $g g^1$ in Q; and through O^1 draw $w O^1 w^1$, parallel to $v Q v^1$, cutting $a^1 c$ in w, and $a_2 g_2$ in w^1; then will the triangle $g Q v$, and the figure $g^1 Q v^1 a^1$, represent the stresses on the voussoir, and the triangles $g^1 O^1 w$ and $g_2 O^1 w^1$ the stresses on the connecting piece due to the bending moment $M^1 = F \times N^1 O$. That is, if o be any point on the line $g g_2$, the intensity of stress at o due to M^1 is represented by o y, the portion of the line through o, parallel to $X O X^1$, lying between $g g_2$ and $v v^1 a^1$, or $w w^1$, as the case may be, such stress being compression or tension according as y lies to the right or left of o. If o lies between g and g^1—that is, in the voussoir—the total intensity at o is represented, as before, by x y, and in this case must always be compression. It will be seen that when y lies between v^1 and a^1, x and y coincide, and therefore x y = nil, showing that for this portion of the breadth of the voussoir there is neither compression nor tension.

When $a v^1 = g^1 O^1$ the maximum intensity on the voussoir will be equal to the maximum intensity on the connecting piece; that is, $a v = g^1 w$.

By the expression "mean intensity of compression on the voussoir" is intended the "mean" between the maximum and minimum intensities of compressive stress on the voussoirs. When v^1 lies between g^1 and a^1 the mean intensity is always equal to $O X = \frac{F}{A}$; but when v^1 lies between a and a^1 the mean intensity is always equal to half the maximum intensity $= \frac{a v}{2}$.

The above investigation is of course purely theoretical, and is based on the assumption of perfect joints—that is, absolutely accurate fitting. Such absolute perfection of workmanship is, however, practically unattainable. It therefore seems to the Author that, when a gate is made of a form such as that shown in Fig. 19, and is consequently subject to the action of a bending moment, then the connecting pieces should be made of sufficient strength to

withstand the whole of that bending moment if necessary. At the same time the voussoirs should be of such dimensions that the "mean" intensity (found in the manner above described) shall not exceed a certain limit, that limit being determined by the engineer according to the timber made use of. In fixing this limit it should be remembered, that the maximum intensity obtained by an analysis such as the foregoing corresponds with the maximum intensity on the compressed fibres of a beam subject to transverse stress, rather than to the intensity on a strut subject to direct stress. In the latter case, the crushing strength of the material being known, it is usual to give a large factor of safety when fixing the working load to be permitted.

Looking, however, at the way in which struts are usually loaded, and the imperfections of fitting, even in the most carefully conducted experimental trials, it may safely be considered that what is usually termed the intensity at the crushing point is really the "mean" of the intensities distributed over the sectional area of the material to be crushed, rather than the true maximum intensity, which is probably much in excess of that recorded by experiment. That is to say, in common practice it is considered that the crushing intensity is equal to the crushing load divided by the sectional area, and that the working intensity is equal to the working load divided by the sectional area; but it is not commonly recognised that the results so obtained are the "mean," and not the maximum, intensities.

In fixing the limiting intensity of stress on the voussoir of a dock gate the engineer must obviously be guided by previous experience, obtained either experimentally or practically; and as the results of such experience will commonly be in terms of "mean" intensities, the Author has suggested the "mean" intensity in the present case as the most convenient for comparison. For instance, if, when designing an ordinary strut, the working intensity is fixed in the common way, at, say, 1,000 lbs. per square inch, then, in the case of a dock gate of the same material, the limit for the "mean" intensity found in the manner described might safely be fixed also at 1,000 lbs. per square inch, notwithstanding that the maximum intensity may be double this.

The divisional, or "voussoir" principle, presents several advantages for dock gates built of timber. The timber used need not be of unusual dimensions; the gates can be built in the workshop, and then readily removed piecemeal to their places; they are easily erected, and, if properly constructed, will stand a considerable amount of rough usage, the last being by no means an unimportant

qualification. Their construction, however, requires careful supervision and skilled workmanship, which in some places may not be readily obtainable.

As regards the general outline of these gates, the foregoing investigations point to the conclusion that, the nearer a gate approaches the form of the true circular arch, the stronger it will be, other things being equal; or, expressing the same thing in another way, with equal strength less material will be required. In many instances, however, the connecting pieces (which obviously cannot be altogether dispensed with) become cumbersome and of awkward shape when the circular arch is adopted; a difficulty which is to a great extent obviated with the pointed arch, the latter form rendering the gate more compact. It will, therefore, frequently be preferable to adopt the pointed, instead of the circular arch, even at the sacrifice of a certain amount of timber, the value of the latter being a mere trifle when compared with the total cost of a dock and its fittings.

In designing a gate of the pointed arch form, care must be taken to keep the bending moment within the limits of the moments of resistance, bearing in mind that as the curve of the gate is flattened so are the bending moments increased. The joints should, of course, be perpendicular to the forces they have to resist; therefore they should be on lines radiating from C, Fig. 5 (page 159). In fitting the gates, since it is impossible to force the heel-post as tight up against the hollow quoin as when the gates are under pressure, it will be best to make them as nearly true as possible, giving a slight preference in favour of "nipping" at the outer (concave) side of the mitre-post; that is, to make the gates apparently very slightly too long. The water pressure and wear at the heel-post will soon bring them to their true form; and in the meantime, in the case of the pointed arch, "nipping" at the outer side of the mitre-post will tend to lessen the bending moment at the centre of the gate.

So far no account has been taken of the general changes of form due to the pliability of the material; and the available data of deformation under pressure, as regards timber, are scarcely reliable enough to enable them to be accurately determined. With wooden gates such as those referred to, it appears to the Author that these changes may safely be neglected, if the strength is calculated on the assumption that the gate is subjected to the extreme condition of "nipping" at the inner side of the mitre-post. When considering the effect of nipping, it must be remembered that accidental nipping will only

occur at isolated points throughout the depth, generally near the surface-level of the water; and the effect will be distributed by means of the vertical framing so as really to amount to but a small fraction of the normal stress. What may be termed structural nipping is of more importance, viz., that caused by the gates being a little too short, or by the faces of the mitre-posts being cut to a wrong angle. Such a state of things gives the condition of "nipping" previously referred to, which should be taken into account in calculating the strength of a gate; but unless gross carelessness has occurred in the fitting, and the faces of the mitre-posts are cut away to an extraordinary degree, the changes due to pliability will not increase the stresses, but rather diminish them.

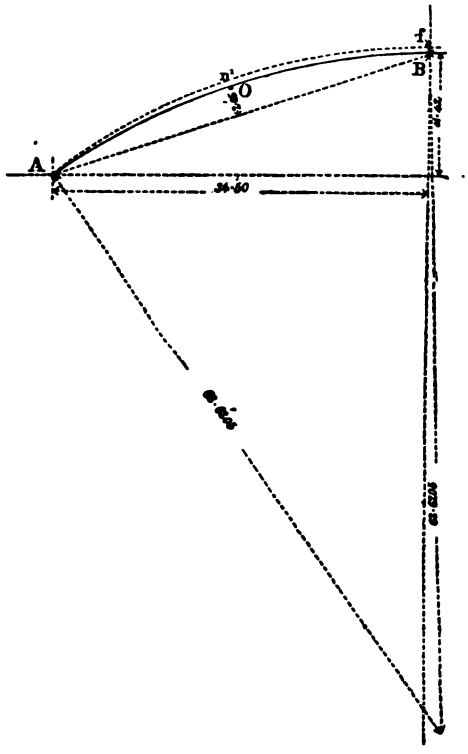
The effect of pliability will be to flatten the curve of the gate when under pressure, and by so much to increase the bending moments; but, at the same time, the meeting face of the mitre-post will have the inner edge drawn back, and the outer edge thrust forward, so that the centre of stress will be transferred from the inner edge to some point nearer the outer edge, and the bending moments will be reduced accordingly, more than counterbalancing the increase due to the flattening of the curve. If, however, it be assumed, for the sake of argument, that the faces of the mitre-posts are so cut away, that under any condition of curvature they can only meet at the inner edges, the change of form due to pliability may increase the stresses on the gate. The effect, then, of the direct acting force F will tend to shorten the neutral axis, but will not alter its form; and the bending moments will alter the form of the neutral axis but will not affect its length; it being understood that by neutral axis is here meant the neutral axis as regards bending moments only, and not of bending moments and direct force combined.

The arc A O B, Fig. 23, represents the neutral axis of a gate when in its normal state, A being the centre of the heel-post, and B the centre of the meeting faces of the mitre-post. The arc A n^1 f shows the line of position of resultants when the gate is nipping at the inner edge of the mitre-post. The bending moments throughout the gate are, therefore, nearly proportional to the distances between these two arcs. That is, they increase from nothing at the heel-post, to a maximum at the centre, and again diminish towards the mitre-post.

The alteration of curvature under pressure will vary with the bending moments, so that the arc A O B will assume a somewhat elliptical form. As it is very flat, however, a close approximation may be obtained by assuming that the alteration varies uniformly,

and that the new form, instead of being elliptical, is that of a circular arc, such as would be caused by the action of a series of uniform bending moments equally distributed throughout the length, and of which the moment at any point is equal to the mean of the actual bending moments on the gate. To be in excess, this may be taken as equal to $\frac{3}{4}$ths of the bending moment at the centre.

FIG. 23.



The bending moment at the centre causes a stress on the convex side of the gate equal to, say, 823 lbs. per square inch, under the condition of nipping at f. Taking $\frac{3}{4}$ths of this, the pressure obtained is, say, 600 lbs. per square inch, as an assumed mean of the maximum intensities on the convex side due to the bending moments.

Then, if R = the radius of the arc A O B under pressure, r = the radius of the arc A O B in the normal state, t = the distance from the neutral axis to the convex side of the gate, I = the mean of

maximum intensities on the convex side due to the bending moments, and E = equal the coefficient of elasticity; the new radius of curvature can be found from the equation $\frac{R + t}{R\left(1 - \frac{I}{E}\right)} = \frac{r + t}{r}$.

In this case, r = 63·6205 feet, t = 0·75, I = 600 lbs. per square inch (assumed), E = 2,000,000 lbs. per square inch (assumed); from which the value of R can be easily ascertained.

The intensity of stress due to the direct acting force will average nearly 400 lbs. per square inch. The arc A O B will therefore be shortened by an amount proportional to this intensity.

If L = the length of arc in the normal state, l = the length of the arc under pressure, i = the intensity of stress due to direct force;

Then $l = L\left(1 - \frac{i}{E}\right) = L\left(1 - \frac{400}{2{,}000{,}000}\right)$.

The chord and versed sine of the arc A O B under pressure will therefore be those of an arc of which l = the length, R = the radius of curvature. Calculating these from the data given, the following results are obtained (Fig. 23).

Arc A O B.[1]

——	Normal state.	Under Pressure.
	Feet.	Feet.
Radius	63·6205	65·3026
Length	36·8540	36·8467
Chord	36·3410	36·3596
Versed sine	2·6500	2·5831
Angle subtended at centre . .	33° 11′ 25″·10	32° 19′ 43″·50

From this it will be seen that the versed sine has been diminished by 0·0669 foot = $\frac{7}{8}$ inch nearly; consequently the distance between the arcs A n^1 f and A O B has been increased at the centre of the gate by this extent, and the corresponding bending moment has been increased by a quantity = F × $\frac{7}{8}$ inch nearly.

The foregoing is of course only an approximation, giving excessive results; it will, however, serve to indicate the method by which the extent of deformation can be ascertained.

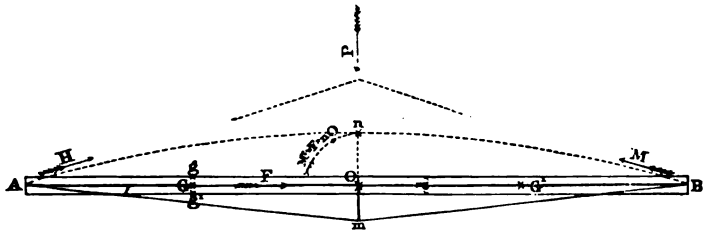
[1] The figures here quoted correspond to the gate referred to in Appendix C.

In the case of trussed beams, the effect of direct compressive stress combined with bending moment has to be considered when applied to a rectangular wooden beam supplemented by wrought-iron truss rods. To illustrate this the simplest form of truss may be taken, namely, that consisting of a rectangular wooden beam, supplemented by two wrought-iron truss rods, and a king-post; and it may be assumed that the king-post is inelastic and of infinite strength. It will occur to the observer that the stresses on the different parts of such a system may vary indefinitely, according to the method of attaching the rods to the beam, and also according to the extent of initial stress put upon the rods before the system is subjected to extraneous pressure. Certain conditions must therefore be assumed before an investigation of the stresses on the different parts can be attempted.

If strength only is considered, the best adjustment appears to be that which, when the system is under pressure, causes the whole bending moment to be borne by the truss rods, and leaves the timber over the king-post entirely free from transverse strain.

The outline of such a system is shown in Fig. 24, the left-hand half of which is drawn to a larger scale in Fig. 26.

FIG. 24.



A O B is the axis of the beam, A m B m are the centre lines of the truss rods, and O m is the centre line of the king-post.

Let F = the direct compressive force along the axis, M^t = the bending moment at O, C = the compressive stress on the beam caused by the action of the truss rods, A = the sectional area of the beam, a = the sectional area of the truss rods, T = the tensile stress on the rods, K = the compressive stress on the king-post, i^t = the intensity of stress on the beam at O, i = the intensity of stress on the rods, $n\,O = \frac{M^t}{F}$, A O = L = the half length of the beam:

Then, since there is no transverse strain on the timber at O, and

the whole bending moment is supposed to be borne by the truss, $C \times m\,O = M^1 = F \times n\,O$, therefore $C = F \times \frac{n\,O}{m\,O}$.

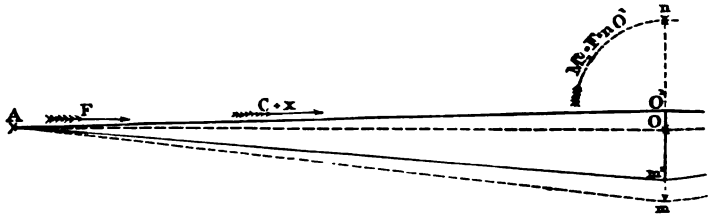
The whole compressive stress on the beam at O is equal to $F + C = F\left(1 + \frac{n\,O}{m\,O}\right)$; from which $i = \frac{F}{A}\left(1 + \frac{n\,O}{m\,O}\right)$.

The tensile stress on the rods is $T = C \times \frac{A\,m}{A\,O} = F \times \frac{n\,O}{m\,O} \times \frac{A\,m}{A\,O}$; from which $i = \frac{F}{a} \times \frac{n\,O}{m\,O} \times \frac{A\,m}{A\,O}$.

The compressive stress on the king-post is $K = 2\,\frac{M^1}{L}$.

It has been assumed that the best adjustment is that which leaves the timber entirely free from transverse strain at O. But suppose this is not the case, and that the rods are tightened up so as to give a camber to the beam, as shown in Fig. 25, in which $A\,O^1$ is the axis of the beam, $A\,m^1$ the centre line of the truss rod, and $O^1\,m^1$ the centre line of the king-post.

FIG. 25.



The dotted lines show the form of the beam as previously assumed. From the former investigation, n O is obviously the distance from O to the line of position of the resultants. Now a small change in the position of O will cause a much smaller change in the position of n, so small, in fact, that it may be neglected, and n may be considered to remain in the same position.

To cause the beam to camber from O to O^1 the tensile stress on the rods must be increased, and, consequently, the longitudinal compressive stress on the beam caused by the rods must also be increased. Let this stress $= C + x$. If $M^1_{\frac{1}{A}}$ = new bending moment at O^1, $= F \times n\,O^1$; then, since $m^1\,O^1 = m\,O$, and from the former investigation $F \times n\,O = C \times m\,O$, therefore $F \times n\,O^1$ must be less than $(C + x)\,m^1\,O^1$. Let $F \times n\,O^1 = (C + x)\,m^1\,O^1 - m^1 = (C + x)\,m\,O - m^1$. From which $F \times n\,O - F \times O\,O^1 = C \times m\,O + x \times m\,O - m^1$, and $m^1 = x \times m\,O + F \times O\,O^1$. m^1 is

clearly the moment of resistance of the timber proportional to the camber. Then $F + C + x$ = the compressive stress along the axis, and m^1 = a bending moment at O^1 will give the stresses on the beam at O^1 under the condition of camber shown in Fig. 25.

The process of cambering has therefore increased the compressive stress on the beam by a quantity = x, and at the same time has imposed upon it a bending moment = $m^1 = x \times m\,O + F \times O\,O^1$. It is therefore obvious that any tightening of the truss rods beyond that necessary to give the conditions first assumed is injurious, and weakens the system.

Let it now be supposed that the truss rods of Fig. 26 are slackened, so that the beam deflects, and assumes the form shown in Fig. 27.

FIG. 26.

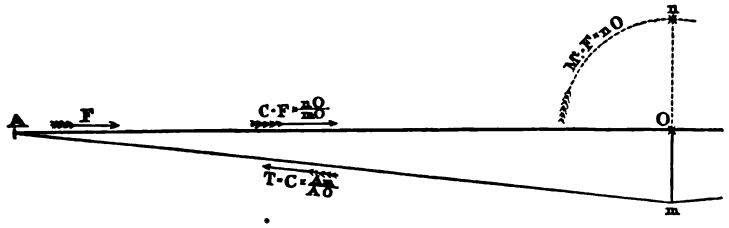
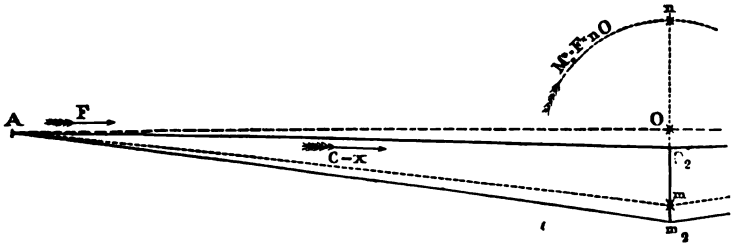


FIG. 27.



By a similar process to the above $F + C - x$ = compressive stress along the axis, and m^1 = a bending moment = $x \times m\,O + F \times O\,O_2$ will give the stresses on the beam at O_2 under this condition of deflection. Allowing the beam to deflect has therefore diminished the longitudinal compressive stress by a quantity = x, but it has imposed on the beam a bending moment = $m^1 = x \times m\,O + F \times O\,O_2$.

If d = the thickness of the timber beam, it can be shown that if m O is greater than $\frac{d}{6}$ then the maximum intensity of stress due

to a bending moment = $x \times m O$ is greater than $\frac{x}{A}$, "A" being the sectional area of the beam. In practice the distance $m O$ is considerably greater than $\frac{d}{6}$, therefore the maximum intensity of stress due to a bending moment = $x \times m O$ is considerably greater than $\frac{x}{A}$, and the maximum intensity due to a bending moment = $x \times m O + F \times O O_2$ must be still greater, and may be taken as $\frac{x}{A} + Z$. But the intensity of the stress due to the compressive forces along the axis has been diminished by a quantity = $\frac{x}{A}$. The total increase of maximum intensity is therefore $\frac{x}{A} + Z - \frac{x}{A} = Z$, and Z is the maximum intensity of compressive stress due to a bending moment on the beam, equal to $m_1' = x\left(m O - \frac{d}{6}\right) + F \times O O_2$.

The maximum intensity of stress on the beam has therefore been increased by allowing it to deflect beyond the position first assumed, and to that extent the system has been weakened. It consequently appears that the best condition of adjustment is the one first assumed, viz., that which, when the system is under pressure, causes the whole bending moment at the centre to be borne by the truss rods, and leaves the timber over the king-post entirely free from transverse strain. It is assumed that the beam is of uniform section throughout its length.

To attain this condition, if the beam is continuous from A to B the system, when under pressure, must have a certain deflection, which is supposed to be the case in Figs. 24 and 26, but, to avoid confusion, has not been shown in the diagrams.

Let v = required deflection at the centre of the beam; L = the half length of the beam = A O (Fig. 24); E_w = the coefficient of elasticity of timber;

$$\text{Then } v = \frac{M' L^2}{E_w A d^2} \quad \ldots \ldots \ldots \ldots \ldots \quad (1)^1$$

The working deflection of the trussed beam should therefore be $\frac{1}{3}$ the deflection that the beam would have if there was

[1] See Appendix D.

system of trussing. If no deflection is permitted, then, from e beam being continuous, the timber over the king-post will be bject to a bending moment in an inverse direction, and the ditions will not be fulfilled. When the pressure is removed system will assume a certain camber, because the elasticity of materials will tend to make the various parts assume their mal proportions. Consequently, the tensile stress on the rods l give rise to a bending moment at the centre of the beam, such ment being in the opposite direction to the action of the load, decreasing in magnitude as the camber increases. To this ion of the truss the beam will offer no resistance until the tre has traversed a space equal to the extent of the previous lection = v, after which any camber that may be given to it by truss will cause a corresponding moment of resistance in the m, acting in a reverse direction to the bending moment of the ss, and which will increase as the camber increases.

The position of equilibrum will be that in which these opposite ments are equal to each other.

Let V = camber at the centre of the beam when in the position equilibrium after all extraneous pressure has been removed; $= m O$; $a_1 = \frac{C}{i}$; E_1 = the coefficient of elasticity of iron; $\frac{a_1 E_1}{a_1 E_1 + A E_w}$.

Then $V + v$ = the total space traversed by the centre of the m in passing from its unloaded to its loaded position.

First, considering the beam; the truss acts through the king-t, and is equivalent to a load at the centre; therefore, if m' = moment of resistance of the beam, $V = \frac{4 m' L^2}{E_w A d^2}$; and

$$= \frac{V E_w A d^2}{4 L^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Secondly, considering the truss: the bending moment when der pressure is $F \times n O$, and at the same time the beam is bject to a compressive stress = F. Now, if it be supposed that F emoved, then, in order to keep the system in the same position, additional bending moment must be applied = $F \times \frac{a_1 E_1}{a_1 E_1 + A E_w}$ $m O = F r m O$. The moment of resistance of the truss, when its position of deflection, but, supposing the load removed, is refore = $F n O + F r m O = F (n O + r m O)$.

If the system now cambers through a distance = $V + v$, the

beam will elongate by a certain quantity, which may be denoted by k, and $k = D \times \frac{a_1 E_1}{a_1 E_1 + A E_w} \times \frac{V + v}{L} = \frac{D r (V + v)}{L}$.

If C^1 = the longitudinal stress on the beam proportional to this elongation, $k = \frac{C^1 L}{A E_w}$; therefore $C^1 = \frac{D r A E_w (V + v)}{L^2}$.

If m^t = the bending moment of the truss in its new position, $m^t = F (n O + r m o) - C^1 \times D$; therefore $m^t = F (n O + r m O) - \frac{D^2 r A E_w V}{L^2} - \frac{D^2 r A E_w v}{L^2}$ . . . . . (3)

But the bending moment of the truss must be equal to the moment of resistance of the beam; therefore, in the position of equilibrium, there is found, from (2) and (3), $F (n O + r m O) - \frac{D^2 r A E_w V}{L^2} - \frac{D^2 r A E_w v}{L^2} = \frac{V E_w A d^2}{4 L^2}$; but $M^t = F \times n O$; and from (1) $v = \frac{M^t L^2}{E_w A d^2}$; therefore $\frac{V \times E_w A (4 r D^2 + d^2)}{4 L^2} = F\left(n O + r m O - r n O \frac{D^2}{d^2}\right)$; from which $V = \frac{F\left(n O + r m O - r n O \frac{D^2}{d^2}\right) 4 L^2}{A E_w (4 r D^2 + d^2)}$.

The condition that there shall be no transverse strain on the timber over the king-post, when the system is under pressure, has been attained by allowing a certain deflection = v. It is, however, by no means intended to convey the impression that this proceeding will relieve every part of the beam from transverse strain. On the contrary, it is only over the king-post that this will be effected, whilst between A and O, or B and O (Plate 2, Fig. 28), the beam will be subject to a series of bending moments varying in magnitude in proportion to the ordinates of the parabolas $A^1 n_1 O^1$, and $B^1 n_2 O^1$, Fig. 29, the vertices of which are at n_1 and n_2, corresponding to G and G_2, points bisecting A O and B O respectively.

If m^t_G = the bending moment on the beam at G = the ordinate $G^1 n_1 = G_2 n_2$; then $m^t_G = \frac{M^t}{4} = \frac{F \times n O}{4}$; and if i_1 = the maximum intensity of the stresses due to m^t_G, then $i_1 = \frac{6 m^t_G}{A d} = \frac{3}{2} \cdot \frac{M^t}{A d}$

Considering compressive stresses as positive, and tensile stresses as negative quantities, the fibres of the beam at G will be subject to stresses caused by m^t_G, the maximum intensities of which will be at g the surface opposed to the load = $i_1 = \frac{3}{2} \frac{M^t}{A d}$; and at g_1 the

face away from the load $= -i_1 = -\frac{3}{2}\frac{M^t}{A\,d}$. But the beam
), and throughout its entire length, is subject to a compressive
ss $= F\left(1 + \frac{n\,O}{m\,O}\right)$, whose intensity at any point is $i = \frac{F}{A}$
$+ \frac{n\,O}{m\,O}\Big)$; therefore if g and g^1 are at the respective surfaces,
way between A and O, the intensity of stress at g is $i + i_1 =$
$1 + \frac{n\,O}{m\,O}\Big) + \frac{3}{2}\frac{M^t}{A\,d} = \frac{F}{A}\left(1 + \frac{n\,O}{m\,O} + \frac{3\,n\,O}{2\,d}\right)$; and at g^1 is
$i_1 = \frac{F}{A}\left(1 + \frac{n\,O}{m\,O} - \frac{3\,n\,O}{2\,d}\right)$.

The intensity of stress at any point on either surface may be gra-
ically represented. For if a scale be made, such that the ordinate
$_1$, of the parabola $A^1\,n_1\,O^1$, in Plate 2, Fig. 29, is equal to
$\frac{3\,n\,O}{2\,d}$, and with this scale the ordinates $A^1\,a$, $A^1\,a^1$, $B^1\,b$, and
^{1} are set off, each equal to $\frac{F}{A}\left(1 + \frac{n\,O}{m\,O}\right)$, and the lines a b, $a^1\,b^1$,
drawn parallel to $A^1\,B^1$, then at any distance $O^1\,x$, on either side
he centre, the intensity of the longitudinal compressive stress
he surface opposed to the load will be equal to $n_3\,y$, the portion
he vertical line passing through x, and intercepted between the
a b and the parabola $A^1\,n_1\,O^1$, or $B^1\,n_2\,O^1$, as the case may be.
o the intensity of longitudinal compressive stress, at the surface
y from the load, will be equal to $n_3\,y^1$, the corresponding
tion of the same vertical line, intercepted between $a^1\,b^1$ and the
abola $A^1\,n_1\,O^1$, or $B^1\,n_2\,O^1$; the lengths being of course mea-
d with the same scale used for setting off $A^1\,a$, and $A^1\,a^1$. It
sumed that the timber beam is of uniform section throughout
length. If the section varies, a corresponding change will take
e in the stresses.

The shearing stress on the timber at A, O, and B, will be
$= F \times \frac{n\,O}{L}$. Commencing at A, and considering those stresses
itive which act against the load, and those negative which act
h the load, then at A there is a shearing stress = S, at B a
aring stress $= -$ S, at O on the side next B = S, and on the
next A $= -$ S. By Mr. Unwin's method, if the line $A^1\,O^1\,B^1$,
e 2, Fig. 30, be drawn, representing the axis of the beam,
being the centre, and the upper side be considered positive,
the lower negative, then, by setting off $A^1\,s$ = S, $O^1\,s^1 = -$ S,

$O^1 s^{II} = S$, $B^1 s^{III} = -S$, and joining s and s^1, s^{II} and s^{III}, a diagram is obtained representing the shearing stresses on the timber at every point, the distances between $A^1 O^1 B^1$, and ss^1, or $s^{II} s^{III}$, measured perpendicular to $A^1 B^1$, giving the magnitude of the stresses.

The total shearing stress on the whole system will be at $A = 2F \times \frac{n O}{L}$, and at $B = -2F \times \frac{n O}{L}$. So that if in Fig. 30 there be made $A^1 S = 2 A^1 s$, and $B^1 S^1 = 2 B^1 s^{III}$ and $S S^1$ be joined, the line $S S^1$ will mark the magnitude of the shearing stress on the whole system at any point, the vertical distances between the lines SS^1 and $s s^1$, $s^{II} s^{III}$, representing the shearing stresses on the rods.

In practice it may not always be desirable to permit any deflection at the centre of the gate, when under pressure. When this is the case, if the timber beam is continuous and of uniform section, using the same notation as before, $C = \frac{5}{4} F \frac{n O}{m O}$, and the longitudinal compressive stress on the beam $= F + C = F\left(1 + \frac{5 n 0}{4 m 0}\right)$, the intensity of which at any point is $i = \frac{F}{A}\left(1 + \frac{5 n O}{4 m O}\right)$.

But owing to the continuity of the beam there is at O, Plate 2, Fig. 31, an inverse bending moment $= \frac{M^1}{4}$, causing an intensity of stress.

At o the surface opposed to the load $-i_m = -\frac{3}{2} F \frac{n 0}{A d}$; and at o^1 the surface away from load, $i_m = \frac{3}{2} F \frac{n O}{A d}$. Therefore the total intensities of stress at o and o^1 under the condition of no deflection will be, at o, intensity $= \frac{F}{A}\left(1 + \frac{5 n O}{4 m O} - \frac{3 n 0}{2 d}\right)$; and at o^1, intensity $= \frac{F}{A}\left(1 + \frac{5 n O}{4 m O} + \frac{3 n O}{2 d}\right)$.

The tensile stress on the rods will be $T = \frac{5}{4} F \frac{n O}{m O} \times \frac{A m}{A 0}$; from which the intensity $i = \frac{F}{a} \times \frac{5}{4} \times \frac{n O}{m O} \times \frac{A m}{A O} = \frac{T}{a}$. The compressive stress on the king-post will be $K = \frac{5 M^1}{2 L}$. The shearing stresses on the timber will be at A, a shearing stress $= \frac{3}{4} F \frac{n O}{L}$; at B, a shearing stress $= -\frac{3}{4} F \frac{n O}{L}$; and at

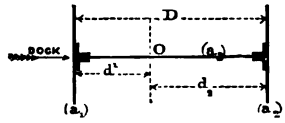
O, the side next B $= \frac{5}{4} F \frac{n O}{L}$, and on the side next A $= -\frac{5}{4} F \frac{n O}{L}$.

The diagram, Plate 2, Fig. 32, shows the bending moments, and intensities at the surfaces of timber, under the condition of no deflection at the centre. Fig. 33 shows the shearing stresses under the same condition. The dotted lines in each case show the intensities, &c., when the system is allowed to deflect at the centre through a distance $= v = \frac{M' L^2}{E_w A d^2}$, being in fact repetitions of Figs. 29 and 30.

The differences between the dotted and full lines indicate the increased intensities and stresses due to the condition of no deflection. Under this latter condition the camber of the beam when pressure is removed will be $V = F \frac{\left(\frac{5}{4} n O + r m O\right) 4 L^2}{A E_w (4 r D^2 + d^2)}$.

Wrought-iron Gates.

In the case of wrought-iron gates, the point to consider is the effect of direct compressive stress combined with bending moment on a wrought-iron girder composed of flanges connected by a centre web.



Let the two flanges and the web be respectively denoted by the symbols (a_1), (a_2), and (a_3), the flange opposed to the load, or back flange, being (a_1), the front flange (a_2), and the web (a_3). Also let a_1, a_2, and a_3 denote the sectional areas of (a_1), (a_2), and (a_3) respectively, so that if the total sectional area is denoted by A, then $A = a_1 + a_2 + a_3$. To calculate the moment of resistance of the beam, the thicknesses of (a_1) and (a_2) may, without appreciable error, be disregarded, and it may be considered that each flange acts at its centre of gravity, so that the effective width of the beam is the distance from the centre of gravity of (a_1) to the centre of gravity of (a_2).

Let this width be denoted by D. The neutral axis of the beam with regard to bending moments lies between (a_1) and (a_2).

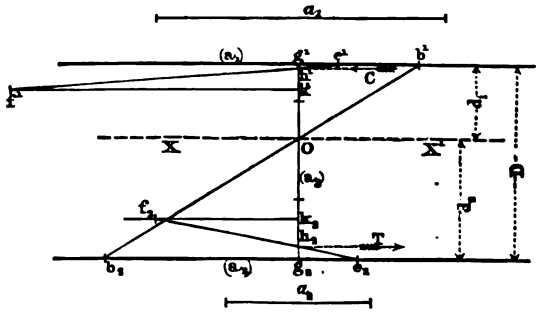
Let d_1 = the distance of this neutral axis from (a_1), and d_2 = the distance from (a_2); then $d_1 = \frac{D}{2} \cdot \frac{2a_2 + a_3}{A}$, $d_2 = \frac{D}{2} \cdot \frac{2a_1 + a_3}{A}$, and $d_1 + d_2 = D$.

It will be seen that this neutral axis corresponds with the centre of gravity of the cross section. The neutral axis with regard to the bending moments must not be confounded with the absolute neutral axis of the beam under the combined action of a bending moment and direct compressive stress. The absolute neutral axis may, or may not, be between (a_1) and (a_2), and its position will depend on the relative proportions of the beam, the bending moment, and the direct compressive stress. If it lies outside the beam it will be an imaginary line, about which, as an axis, the beam at the corresponding cross section will have a tendency to bend.

It may be assumed that the beam is constructed in such a manner that the plane of action of the forces corresponds with the plane of the web, and that the flanges are perpendicular thereto. That is to say, in the case of a dock gate it is assumed that the webs are horizontal and the flanges vertical.

In Fig 34 let $g_1 g_2$ be the line of cross section under consideration, which it will be convenient to take on a line radiating from

FIG. 34.



C, Fig. 5 (page 159); and let g_1 be at the centre of gravity of (a_1), g_2 at the centre of gravity of (a_2), so that the length $g_1 g_2 = D$. Assuming that the web is of uniform thickness throughout its width, the sectional area of the web is proportional to the length D, and it is easy to draw to the same scale lines a_1 and a_2, whose lengths shall be proportional to the areas a_1 and a_2 respectively.

Draw $g_1 b_1$ and $g_2 b_2$ perpendicular to $g_1 g_2$, and make $g_1 b_1$

proportional to $a_2 + \frac{a_3}{2} = f\left(a_2 + \frac{D}{2}\right)$, and $b_2 g_2$ proportional to $a_1 + \frac{a_3}{2} = f\left(a_1 + \frac{D}{2}\right)$, f being any number or fraction.[1]

Draw the straight line $b_1 b_2$ cutting $g_1 g_2$ in O, and through O draw $X O X^1$ perpendicular to $g_1 g_2$. Then will $X O X^1$ be the neutral axis of the cross section with regard to the bending moments, and $O g_1 = d_1$ and $O g_2 = d_2$.

The effect of a bending moment will be that every portion of the cross section on one side of $X O X^1$ will be subject to compressive stress, and every portion on the other side to tensile stress, the intensity of stress on any fibre being directly proportional to its distance from $X O X^1$. The total compressive stress due to the bending moment is equal to the total tensile stress caused thereby; and if the former is denoted by C, and the latter by T, then T = C.

Make $g_1 k_1 = \frac{d_1}{3}$, and $g_2 k_2 = \frac{d_2}{3}$; draw $k_1 f_1$ and $k_2 f_2$ parallel to $X O X^1$; make $g_1 e_1$ proportional to $\frac{a_3}{2} \cdot \frac{d_1}{D} = \frac{d_1}{2}$; $k_1 f_1$ proportional to $a_1 = a_1$; $k_2 f_2$ proportional to $a_2 = a_2$; $g_2 e_2$ proportional to $\frac{a_3}{2}\frac{d_2}{D} = \frac{d_2}{2}$; and draw the straight lines $e_1 f_1$, and $e_2 f_2$, cutting $g_1 g_2$ in h_1 and h_2 respectively. Then h_1 is the centre of action of all the stresses caused by the bending moment on the same side of O as (a_1). Similarly h_2 is the centre of action of all the stresses caused by the bending moment on the same side as (a_2).

If the bending moment produces compressive stress on the side next (a_1), then the moment of resistance is equivalent to a force C acting at h_1 plus a force T acting at h_2.

If M^t = the bending moment, $M^t = C \times h_1 O + T \times h_2 O = C$ or $T \times h_1 h_2$. Let i_c = the intensity of stress on (a_1) due to M^t, and i_t = the intensity of stress on (a_2) due to M^t; then $C = i_c\left(a_1 + \frac{a_3}{2} \cdot \frac{d_1}{D}\right) = T = i_T\left(a_2 + \frac{a_3}{2} \cdot \frac{d_2}{D}\right)$. From the construction $h_1 h_2 = \frac{2}{3} D + \frac{d_1}{3} \frac{a_1}{a_1 + \frac{a_3}{2}\frac{d_1}{D}} + \frac{d_2}{3} \frac{a_2}{a_2 + \frac{a_3}{2}\frac{d_2}{D}}$; therefore

$$M^t = \frac{i_T D}{6} \times \left\{ \frac{4 a_2 \cdot A + (2a_1 + a_3)(a_2 + a_3) + a_1 (2 a_2 + a_3) \frac{d_1}{d_2}}{A} \right\}$$

[1] In Fig. 34 $f = \frac{1}{2}$.

$$i_T = \frac{M'}{D} \times \frac{6\,A}{4\,a_2\,A + (2a_1 + a_3)(a_2 + a_3) + a_1\,(2\,a_2 + a_3)\frac{d_1}{d_2}}\,;\ \text{and}$$

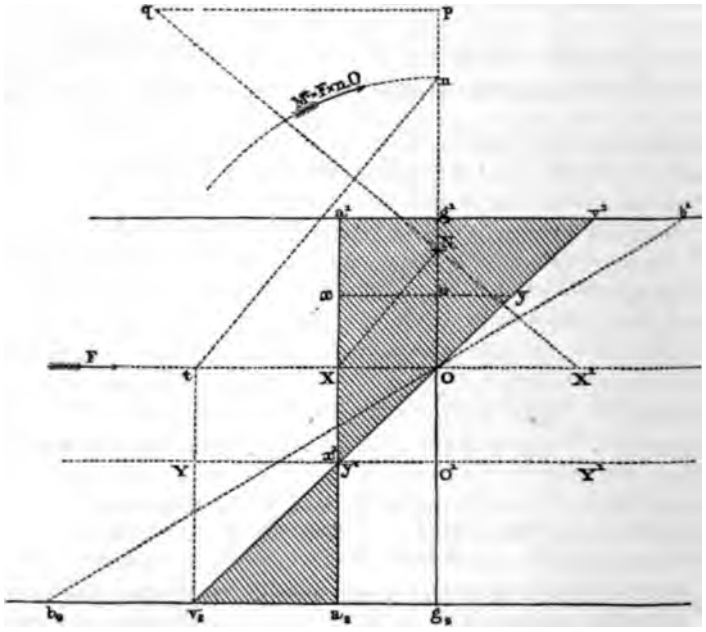
$$i_c = i_T \cdot \frac{d_1}{d_2}.$$

If F = the direct compressive force, i_F = the intensity of stress due to F, i_1 = the total intensity on (a_1) due to M' and F, and i_2 = the total intensity on (a_2) due to M' and F; then $i_F = \frac{F}{A}$, $i_1 = i_F + i_c$, and $i_2 = i_F - i_T$.

By referring to the values of C and T, it will be seen that if $M' = F \times h_1\,h_2 \times \frac{a_2 + \frac{a_3}{2}\frac{d_2}{D}}{A}$, then $i_T = i_F$. Hence it is easy to draw a graphic representation of the intensities due to any bending moment.

In Fig. 35, which is a repetition of Fig. 34, with some of the

FIG. 35.



work omitted to avoid confusion, make O X = $\frac{F}{A}$, and draw a_1 X a_2 parallel to g_1 g_2.

Then, as in the previous cases, the parallelogram $g_1\ a_2$ is a graphic representation of the intensities due to F. The intensity i_y at any point o being represented by o x, the portion of the line through o, parallel to X O X^1, and lying between $g_1\ g_2$ and $a_1\ a_2$. Continue the line $g_2\ g_1$ to p, and make O p = $h_1\ h_2$; draw p q perpendicular to O p; make O X^1 proportional to $a_2 + \frac{a_3}{2}\frac{d_2}{D} = f^1\left(a_2 + \frac{d_2}{2}\right)$, and p q proportional to $a_1 + a_3 \cdot \frac{d_1 + \frac{d_2}{2}}{D} = f^1\left(a_1 + d_1 + \frac{d_2}{2}\right)$, f^1 being any number or fraction.[1] Draw X^1 q cutting O p in N. Then O N = $h_1\ h_2 \times \frac{a_2 + \frac{a_3}{2}\frac{d_2}{D}}{A}$, and if M^t = F × N O, therefore $i_T = \frac{F}{A} = i_y$ = O X.

If M^t is greater or less than F × N O, then on line $g_2\ g_1$, produced if necessary, find a point n such that M^t = F n O.

Draw N X, and parallel thereto draw n t, cutting X O X^1 in t. Draw t v_2 parallel to $g_1\ g_2$, and cutting $b_2\ g_2$ in v_2; then $g_2\ v_2$ represents the intensity on (a_2) due to M^t, *i.e.* $g_2\ v_2 = i_T$. Through O draw the straight line v_2 O v_1, cutting $g_1\ b_1$ in v_1; then $g_1\ v_1$ represents the intensity of stress on (a_1) due to M^t, *i.e.* $g_1\ v_1 = i_c$.

The line $v_1\ v_2$ marks the intensities due to M^t = F × n O. That is to say, at any point o between g_1 and g_2 the intensity due to M^t is represented by o y, the portion of the line through o, parallel to X O X^1, lying between $g_1\ g_2$ and $v_1\ v_2$, such intensity being compression or tension according as y lies to the right or to the left of o. The total intensity of stress on the fibres of the beam at any point o is represented by x y, such total intensity being compression or tension according as y lies to the right or to the left of x. At O^1, the point corresponding to the point of intersection of the lines $a_1\ a_2$ and $v_1\ v_2$, x^1 O^1 = − O^1 y^1, and x^1 O^1 + O^1 y^1 = nil. Therefore at O^1 there is neither tension nor compression; and if through O^1 the line Y O^1 Y^1 be drawn, parallel to X O X^1, then Y O^1 Y^1 is the absolute neutral axis of the beam, under the combined influence of F and M^t = F × n O. It is obvious that if M^t is less than F × N O, then O^1, and consequently Y O^1 Y^1, will lie outside the beam.

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[1] In Fig. 35 $f^1 = \frac{1}{2}$.

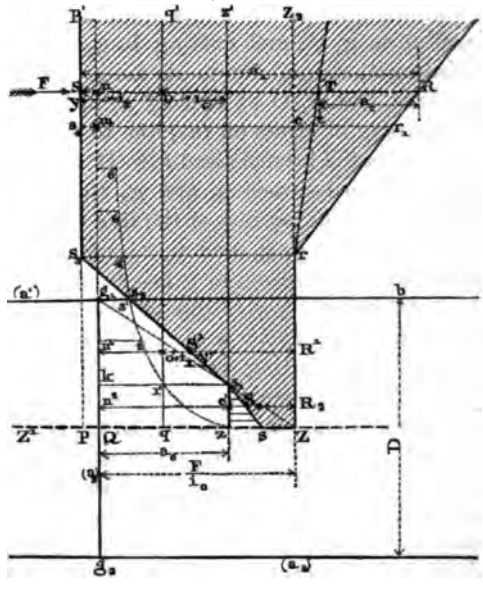
If the web is of open lattice work, or is so small compared with the flanges that it may be disregarded, then $i_1 = \frac{F}{a_1} \cdot \frac{n\,g_2}{D}$, and $i_2 = \frac{F}{a_2} \frac{n\,g_1}{D}$.

If n lies between g_1 and g_2, then i_2 has a positive sign, showing that (a_2) is under compression; but when n is beyond g_1, then i_2 has a negative sign, and (a_2) is subject to a tensile stress.

The foregoing shows a method of finding the intensities of stress on a given section. It remains to be shown how to design a section of such proportions, that the intensity of stress on any fibre shall not exceed certain limiting intensities of tension or compression.

Let it be assumed that the general outlines of the gate have been decided upon, the line of position of resultants with reference thereto ascertained, and the magnitude of F determined, the result being that a beam has to be designed whose breadth is

FIG. 36.



g_1 g_2 (Fig. 36), capable of resisting a force F acting at a point n on the line g_1 g_2, and in a direction perpendicular thereto.

Let i_c = the limiting intensity for compressive stress, and

i_T = the limiting intensity for tensile stress, using the same notation as before. The first point for consideration will be the web (a_3). This will have to be designed with reference to the other requirements and conditions of the gate, rather than to the stresses caused by the water-pressure, except so far as shearing stresses are concerned, the requisite area to resist which can be easily determined by the ordinary methods. Practically, on account of the various contingencies to which a gate is subject, it will be advisable not to reduce the thickness of the web beyond a certain limit, which will usually exceed that theoretically required to resist shearing stresses. The thickness, and consequently the sectional area of the web, therefore become a question for the personal experience of the engineer, and must be determined accordingly, bearing in mind that the smaller the web the less will be the total sectional area required.

If the web is of open lattice work, then, so far as affects the flanges, $a_3 = o$; and if n lies between g_1 and g_2, then $a_1 = \frac{F}{i_c}\frac{n\,g_2}{D}$, and $a_2 = \frac{F}{i_c}\frac{n\,g_1}{D}$.

If n lies beyond g_1, as in Fig. 36, then $a_1 = \frac{F}{i_c}\frac{n\,g_2}{D}$, and $a_2 = \frac{F}{i_T}\frac{n\,g_1}{D}$.

In most cases the practical method will be to disregard the web, and to find the dimensions of (a_1) and (a_2) as above, thus throwing in the web as a margin of strength. When, however, the bending moment is small, and the stresses comparatively light, as in the upper portions of a gate, it may be desirable to take the web into consideration.

Referring to Fig. 36: draw Z^1 Q Z perpendicular to and bisecting g_1 g_2 in Q. To any scale make Q Z = $\frac{F}{i_c}$, and to the same scale make Q z = a_3. Bisect Q z in q, and z Z in s. Make q p = q z $\frac{i_T}{i_c}$, and draw p p′, q q′, z z′, and Z r Z_2 all parallel to g_1 g_2. Draw the straight line g_1 Z cutting z z^1 in s_1. On the line g_1 b, parallel to Q Z, make g_1 s_2 = $\frac{Q\,z}{4}$. Join s s_1, and through s_2 draw the straight line s_1 s_2 s_3, cutting p p^1 in s_3. Draw s_3 r parallel to Q Z, cutting Z Z_2 in r. Make s_3 s_4 (on line p p^1) = $f \times D$, and

draw s_4 m c t r_1 parallel to Q Z, and cutting g_1 g_2 in m, and Z Z_1 in c.[1] Make m r_1 = Q Z $(1+f)$, and t r_1 = c r_1 · $\frac{i_s}{i_T}$. Draw r r_1 and r t, and produce them to any required length. Then, if F acts at any point n, on the line g_1 g_2, lying on the (a_1) side of Q, through n draw S n T R, parallel to Q Z; and the portion S R of such line, intercepted between lines Z r r_1 and s s_1 s_3 p^1, will represent the required area of (a_1).

Also the portion T R will represent the required area of (a_2) when n lies beyond s_3 r; that is to say, if Q z = a_3, then S R = a_1, and T R = a_2, when F is at point n. If F acts between s_3 r and k s_1, then T R disappears, and no flange is required at g_2. For instance, suppose F acts at n^1, then a_3 = Q z, a_1 = S^1 R^1, and a_2 = o, when F is at point n^1.

If F acts between k s_1 and Q Z, then a_2 must equal the portion of the line of action of F intercepted between z s_1 and s s_1, and (a_2) is subject to compressive stress. For instance, a_3 = Q z, a_1 = S^2 R^2, and a_2 = S^2 c^1, when F is at point n^2.

If it be considered that p q = i_T, and q z = i_s, then, if S R cuts q q^1 in o, the intensity of the stress on (a_2), or at g_2, is equal to o y, the portion of S R intercepted between q q^1 and z s_1 s_3 p^1, and is tension or compression according as y lies to the left or right of o. The intensity of stress on (a_1) never exceeds i_s = q z. The curve z, 1, 2, 3, &c., represents the magnitude of the forces which the web alone is capable of resisting at the various distances from Q, keeping the intensity of stress at g_1 always equal to i_s.

In Fig. 36, Q z has been shown less than Q Z. The same method will apply if Q z is greater than Q Z, as is shown in Fig. 37. If n lies on the g_2 side of Q, the whole must of course be reversed.

The above investigation treats the system as if it was a girder with only one web, whereas a gate, of course, has several webs. In computing the strength, a gate may be either taken as a whole, and then proportioned throughout its vertical height in the manner described in Appendix A, or it may be divided into horizontal layers, and the strength of each layer be computed separately. Whichever course is adopted, the methods above given will be equally applicable.

Passing now to the general form of a wrought-iron gate: when

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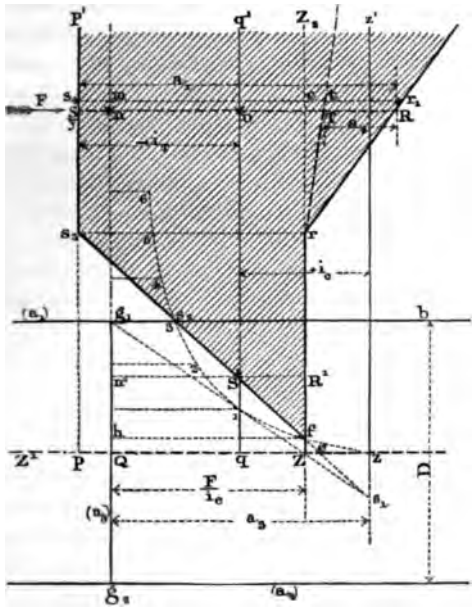
[1] f being any number or fraction.

the method of finding the principal stresses, as previously explained, is considered in connection with the effect of a bending moment, there can be no doubt but that, theoretically at least, the most advantageous form is that on which the water-pressure produces

FIG. 37.[1]



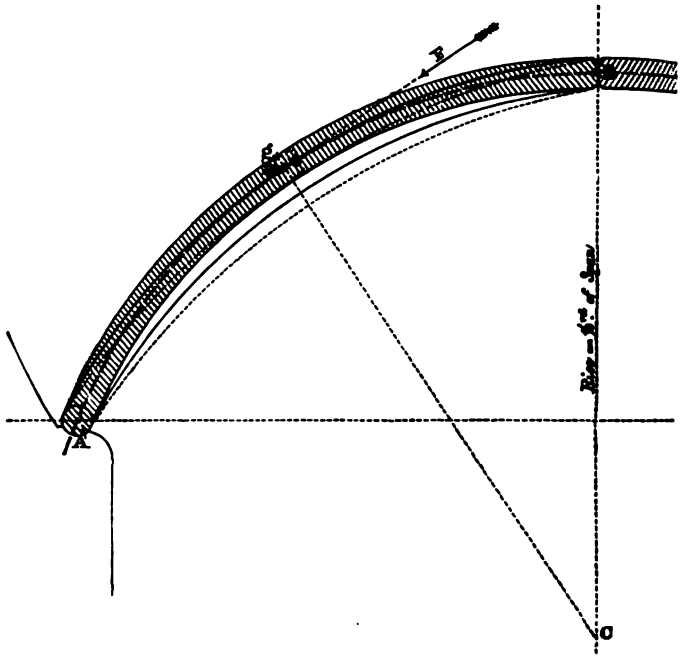
no bending moment; that is to say, when the line of the centres of gravity of the cross sections corresponds with the centre line of the gate, and when the centre lines of both gates form together one continuous arc of a circle extending from centre to centre of the heel-posts, and passing through the centre of the meeting faces of the mitre-posts. Such a gate, for example, as is shown in Fig. 38, the centre line of which is the arc A m B, having its centre at C.

In this case the arc A m B will not only be the line of position, but will also be the line of direction of the resultants; that is to say, the resultant force, acting on a vertical section of the gate, taken on any line C m g radiating from C, through a point g on the back of the gate, will be of a magnitude proportional to C g,

[1] In this case, when F acts between h f and Q Z, R will lie to the left of S, consequently S R becomes a negative quantity. In practice, however, a minus quantity cannot be added, and the result is an excess of strength, which is evident when F acts on the centre line Q Z.

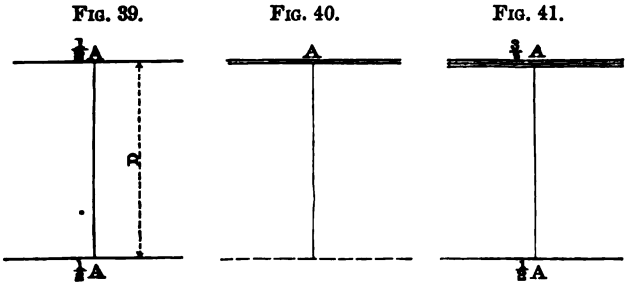
and will act in the direction of the tangent to the arc A m B at m. For if this be not the most advantageous form, assume it as the normal form of the gate. Then, if i_c be the limiting intensity of compressive stress per unit of area, the normal section will have an area $= \frac{F}{i_c}$, proportional to, and which, for comparison, may be called equal to, $\frac{C\,g}{i_c} = A$.

FIG. 38.



Suppose the normal section to have the proportions, theoretically, most favourable for resisting a bending moment, viz., the web a theoretical line, and the flanges each $= \frac{A}{2}$, as shown in Fig. 39 (see next page). Now if the gate is flattened by half the breadth of itself, so that at the middle the back coincides with the arc A m B, as outlined in Fig. 38, then, with this altered form, the line of direction of the resultants will still virtually be the arc A m B, and a bending moment will have been introduced $= \left(C\,g - \frac{D}{2}\right) \times \frac{D}{2}$. But practically $\frac{D}{2}$ is very small compared with C g, so that for a rough

comparison the bending moment may be considered as $C\,g \times \frac{D}{2}$, equivalent to a moment of resistance $= i_c \frac{A}{2} \times D$, that is, a moment of resistance equivalent to that of one of the normal flanges. The result is, that at the centre of the gate the whole of the concave flange, or skin, will have to be done away with, and the convex flange doubled, as shown in Fig. 40, the total sectional area



remaining the same. The extent by which the length of the gate is diminished is so small, that it can scarcely be appreciated. Here, then, with this small amount of flattening, the quantity of metal in the gate may be said to be the same as in the normal form, but it is distributed much more awkwardly. At the heel and mitre-posts the sections will remain nearly as in the normal case, while at the centre the convex flange, or skin, will be doubled, and the concave reduced to a minimum, involving various thicknesses of plates, and other practical inconveniences. On the other hand, in the normal gate, with the same quantity of metal, the flanges will be symmetrical; the same thickness of plates, the same angle irons, the same rivets, &c., will apply on both faces. But what is more important, in the upper portions, where the stresses are small, nearly the whole of the metal could be put into the webs, and only sufficient flanges be allowed to attach planking to. This in the altered form could not be the case, as sufficient flanges must be provided to resist the action of the bending moment; and, as the upper webs cannot be altogether omitted, an increase of metal must result.

Carrying the assumption still farther, and assuming that the gate is flattened by the whole breadth, as shown by the dotted lines in Fig. 38, there is now a bending moment nearly equal to $C\,g \times D$, equivalent to a moment of resistance $= i_c A \times D$, the result being that at the centre of the gate the whole of the original

concave flange will have to be done away with, and be replaced by a flange, or skin, capable of bearing a tensile stress equal to the original compressive stress. Practically, this flange will have the same area as in the normal section, while the convex flange will be trebled in area, the altered gate at the centre being approximately twice the normal sectional area, as in Fig. 41. The total quantity of metal in the whole gate will thus be increased by about one half. If to this be added the increase in the upper webs before mentioned, it will be clearly seen, without going more minutely into the question, that the increase of metal will be rapid as the gate is flattened. Neither will there be any appreciable reduction in the cost per ton until the gate is reduced to the absolutely straight form, when the increase of metal will, in the Author's opinion, more than counterbalance the decrease in price supposed to arise from the use of unbent plates.

As regards the "rise," Mr. Bramwell[1] has pointed out that the most economical form of gate is that in which a pair of gates, when shut, form a continuous arc, subtending an angle of 133° 56′ at the centre of the circle of which the said arc forms a part. The "rise" of the gates is thus equal to the width from centre to centre of the heel-posts, multiplied by 0·32958; in round figures, when the "rise" equals $\frac{1}{3}$ the span. The gates shown in Fig. 38 are drawn with a "rise" such as is above indicated.

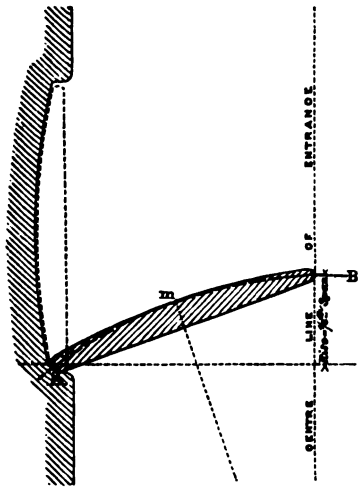
Hitherto no notice has been taken of the variations of stress due to alteration of form when under pressure. Any analysis of such variations must necessarily be complicated. It appears to the Author that it would be useless to attempt to arrive at any general form for such investigation, as every gate must have its own individual peculiarities, which would inevitably vitiate the result. Practically, if the strength of a gate is calculated on the bases of the extreme cases of nipping at the inner and outer edges of the mitre-post, the increased stresses due to alteration of form under pressure may be safely ignored.

Setting aside theory, it must be remembered that the most economical is not necessarily the most advisable form for a pair of dock gates. The gate is the most important part of a dock, but it is a comparatively small item of the cost, and its outlines should be designed with a view to the general convenience and requirements of the situation, rather than to the structural economy of the gate itself. Gates with a large "rise," and sharply curved backs, require deep recesses in the side walls, which are not always

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxi., p. 344.

admissible. A deep bay in the fair line of the side wall when the gate is open is also a source of inconvenience to ships passing through, and is generally to be avoided, if practicable. The Author is of opinion that a convenient form for small and medium-sized gates, say up to 60 feet clear span, is that shown in Fig. 42. In this gate the line of direction of the resultants is the continuous

FIG. 42.



arc A m B, passing through the centres of the heel-posts and of the meeting faces of the mitre-posts, and having its centre on the centre line of the entrance, the "rise," or versed sine of this arc, being $\frac{1}{8}$th of the span from centre to centre of the heel-posts. The back of the gate is the arc of a circle of such a radius, that at the middle of the gate m it coincides with the arc A m B. The front of the gate is a straight line from the heel to the mitre-post. The sectional area of plating on the back of the gate at m would practically be $\frac{F}{i_c}$, and at the heel and mitre-posts, $\frac{1}{2}\frac{F}{i_c}$. The plating on the front of the gate would be, at the heel and the mitre-posts, $\frac{1}{2}\frac{F}{i_c}$; while at the centre no plating would be necessary, unless for flotation purposes, and to enable the gate to stand the stresses brought on it during the processes of opening and shutting. Probably, in practice, the front plating would be made $\frac{1}{2}\frac{F}{i_c}$ throughout the entire length from the heel to the mitre-post. With this form,

the recesses in the side walls will not be inconveniently large; the faces of the gates, when open, will (with the ordinary fenders) be in line with the side wall of the entrance, and the gangway at the top will form one straight path with the coping of the side wall, no small convenience for the gate-men and others carrying heavy warps backwards and forwards. As to the gate itself, the form would allow space for workmen to obtain access to the interior for repairs, &c., if necessary; and the width would give considerable flotation power, if such could be utilised. Moreover, the straight face would permit of the gate being braced diagonally from the top of the heel-post to the foot of the mitre-post, and thus enable the greater part of the weight to be sustained by the anchor strap to the relief of the roller.

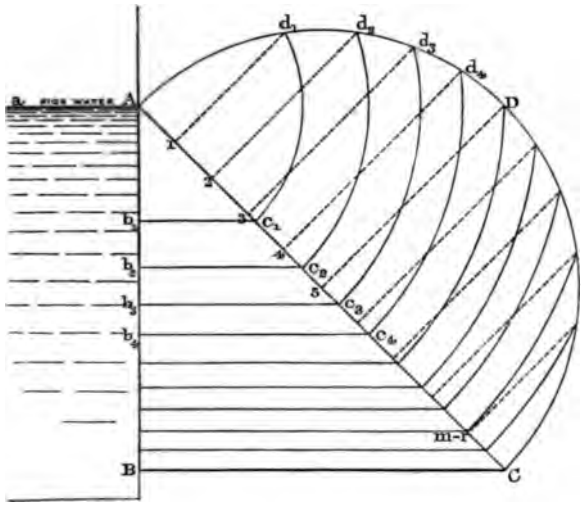
The communication is illustrated by numerous sketches, from which Plate 2 and the woodcuts have been engraved.

APPENDIX A.

lesigning a dock gate it is often convenient, as a guide to the distribution of erial, to divide the vertical section into layers sustaining equal pressure. The owing method of doing this may be useful.

f the sill is not submerged, draw A B representing a vertical section of the

FIG. 1.



te, and at right angles to A B, draw A a representing the highest water level, C representing the level of the sill; make B C = A B, and join A C.

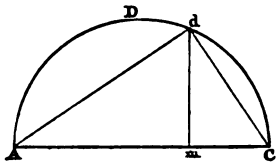
Mark off the points 1, 2, 3, 4 . . . m − 1, dividing the line A C into the reired number of equal parts. On A C describe the semicircle A D C, and from ints 1, 2, 3, 4 . . . m − 1, draw lines perpendicular to A C, cutting the semiicle A D C, in d_1, d_2, d_3, d_4, &c.; then with centre A describe the arcs $d_1 c_1$, $d_2 c_2$, c_3, $d_4 c_4$, &c., cutting A C in c_1, c_2, c_3, c_4, &c. Parallel to B C draw the horiontal lines $c_1 b_1$, $c_2 b_2$, $c_3 b_3$, $c_4 b_4$, &c. These lines will divide A B in the required anner. That is to say, if the total pressure on A B = p, the pressure on each the parts A b_1, $b_1 b_2$, $b_2 b_3$, $b_3 b_4$, &c. $= \frac{p}{m}$; m being the number of parts into hich A C was divided.

If the sill is submerged, it is obvious that the above method will only apply to e part of the gate above the surface level of the outer water. The submerged rtion, is subject to uniform pressure, and can readily be divided into any quired number of equal parts.

The proof of the above depends on the fact that if A C be any given finite right line, and A D C a semicircle described thereon; then if A C is divided into any two parts at m, and from m a line be drawn perpendicular to A C, cutting the semicircle A D C in d, the point d is such that, joining A and d by the straight line A d,

$$\frac{A\,d^2}{A\,C^2} = \frac{A\,m}{A\,C}$$

Fig. 2.

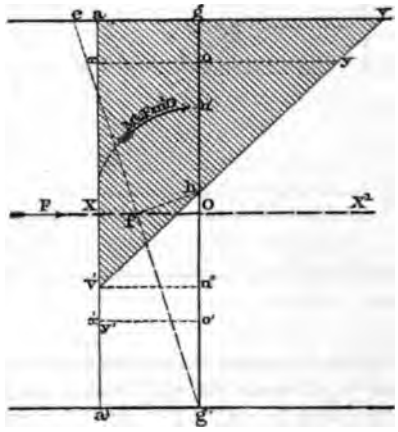


APPENDIX B.

Case 2, A.—If M^1 exceeds $F \times \frac{g\,g^1}{6}$ but is less than $F \times \frac{g\,g^1}{2}$.

The method of arriving at the stresses given in the foregoing Paper will perhaps be better understood if the principle adopted in Case 1 is carried out also in this.

Fig. 3.



Let X O X¹ be the tangent to the axis at O; g O g¹ the line perpendicular to X O X¹ representing the joint under consideration; A = the sectional area of the joint; F = the force acting along X O X¹; and M^1 = the bending moment round O.

Make $X\,O = \frac{F}{A}$, and draw a X a¹ parallel to g O g¹, a g v, and a¹ g¹ parallel to X O X¹.

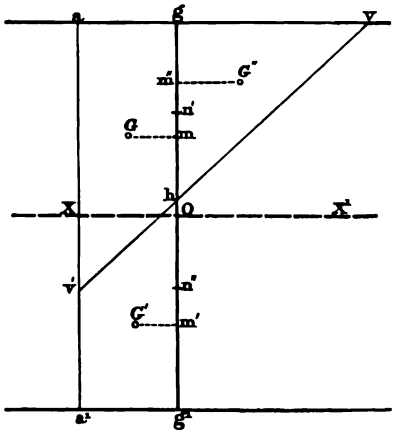
Then, as in Fig. 16 (page 169), the parallelogram a g¹ will be a graphic representation of the compressive stress due to F, the intensity of which per unit of area of the joint, at any point o, is represented by $x\,o$, the portion of the line through o parallel to X O X¹, lying between a a¹ and g g¹. If M^1 tends to turn from left to right, as before:

Between O and g take the point n^1, such that $F \times n^1 O = M^t$, and make $g n'' = 3 g n^1$; draw $n'' v^1$ parallel to $X O X^1$, cutting $a a^1$ in v^1. On line a v to left of g, make $g e = a^1 v^1$, join $g^1 e$, cutting $X O X^1$ in f. Draw f h perpendicular to $g^1 e$ and cutting $g g^1$ in h. Through h and v^1 draw the straight line v h v^1, cutting a g in v. Then will the area of g h v = the area of $g^1 h v^1 a^1$; and the triangle g h v will represent the compressive stress, and the figure $g^1 h v^1 a^1$ the tensile stress due to M^t. The intensity of stress due to M^t per unit of area of the joint, at any point o, will be represented by o y, the portion of the line through o parallel to $X O X^1$ lying between $g g^1$ and $v v^1 a^1$, such stress being compression or tension according as y lies to the right or left of o.

The total intensity at any point o is represented by the line x y, and in this case must always be compression.

It will be noted that of the line $v v^1 a^1$ the part $v^1 a^1$ coincides with the line $a a^1$ consequently when o lies between n'' and g^1, x will coincide with y, and $x y$ = nil, so that for this portion of the joint there is neither tension nor compression.

PROOF (FIG. 4).



$M^t = F \times n^1 O$, and F is proportional to the area of $a g^1$, so that if D^1 = the vertical depth of the joint, $M^t = D^1 \times a g^1 \times n^1 O$.

Therefore $\frac{M^t}{D^1} = a g^1 \times n^1 O$.

Let G be the centre of gravity of g a v^1 h, G^1 of $g^1 a^1 v^1$ h, G'' of g h v.

Draw G m parallel to $X O X^1$, cutting $g g^1$ in m,
G' m' " " " " m^1
G'' m'' " " " " m''.

Then $a g^1 \times n^1 O = (g^1 a^1 v^1 h \times m^1 n^1) + (g a v^1 h \times m n^1)$.

But $g a v^1 h \times m n^1 = g h v \times m'' n^1$, and g h v = $g^1 a^1 v^1$ h.

Therefore $a g^1 \times n^1 O = (g h v \times m'' n^1) + (g^1 a^1 v^1 h \times m^1 n^1)$, $= g h v \times (m'' n^1 + m^1 n^1)$, $= g h v \times m^1 m''$, $= (g h v \times m^1 O) + (g h v \times m'' O)$, $= (g h v \times m'' O) + (g^1 h v^1 a^1 \times m^1 O)$.

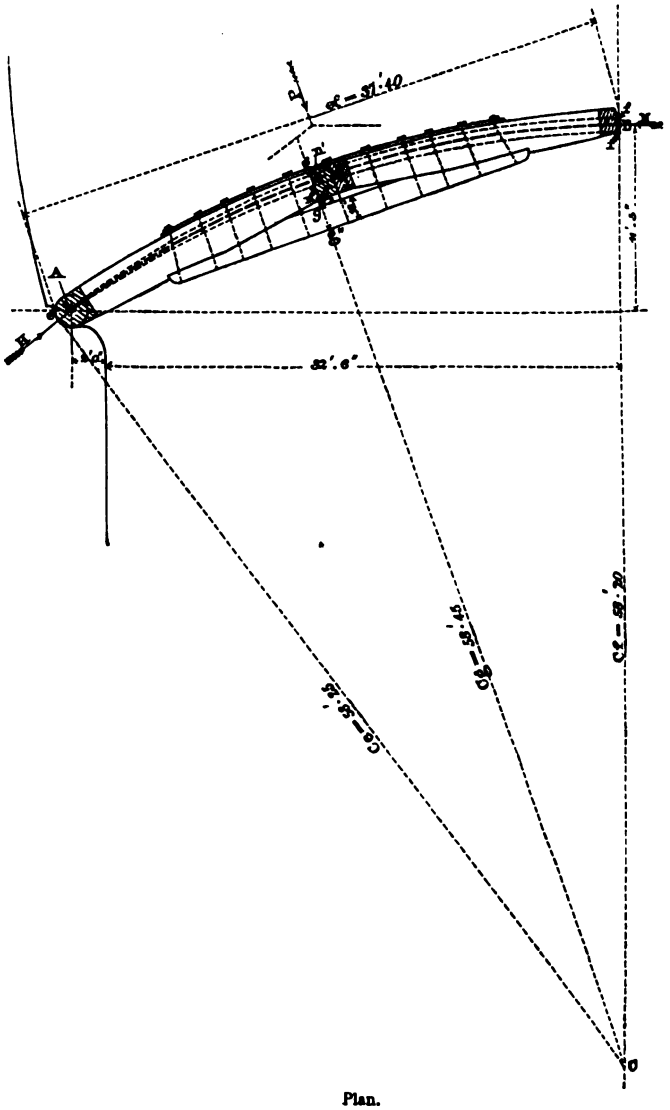
Therefore g h v, and $g^1 h v^1 a^1$, represent the forces produced by the bending moment; that is, together they = $\frac{M^t}{D^1}$.

APPENDIX C.

THE following example shows the practical application of the method of ascertaining the stresses on a dock gate described under Case 2, B.

Fig. 5 and Fig. 6 show the plan, section, and principal dimensions of a dock

FIG. 5.



Plan.

structed of greenheart timber. Taking the lineal foot, the cubic
veight as the units of measure and weight for the primary forces,
age 157, p = pressure per
f gate; p = pressure per
te; W = weight of water
sure, = say 64·5 lbs. per
lepth of sill below highest
: 34 feet (Fig. 6).
nsidered that the outer
ill entirely dry; therefore
·25 lbs. × 34 × 34 =

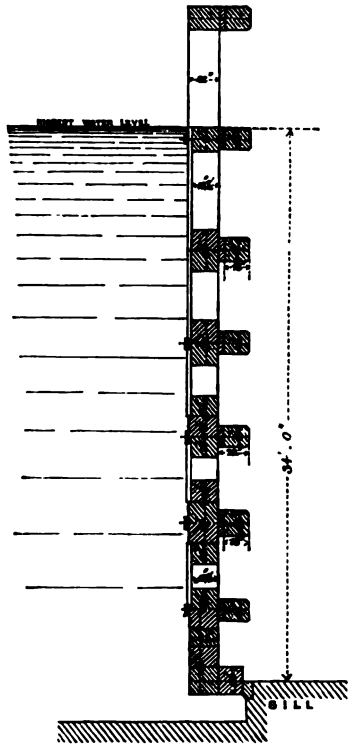
orces are, P = the water
ie reaction on the mitre-
action on the heel-post.
nstance, from plan Fig. 5,
C f = 58·20 feet; C e =

p × e f = 37,281 lbs. ×
9 lbs.; M = p × C f =
0 = 2,169,754 lbs.; H =
lbs. × 58·25 = 2,171,618

ie normal line of position
is the arc A n B, having
nd this may vary to the
arc A n'' f' according as
ie inner or outer edges of

mal arc A n B as the line
resultants, and consider-
n the joint between the
cal framing at g g'; if R
' all the forces acting on
e of the joint g g', R =
× 58·45 = 2,179,074 lbs.

FIG. 6.



Section.
Scale for Figs. 5 and 6, 12 feet = 1 inch.

i. Θ, F = R cos. Θ.
the line radiating from C, and is consequently perpendicular to
e R acting at n, therefore Θ = 0°; and S = 0, showing that
ig stress in the plane of the joint; F = R = 2,179,074 lbs.
he point at which g g' intersects the centre line of voussoirs,
= F × n O.
ing the bending moments and intensities of stress, it will be
pt 1 inch as the unit of measure instead of 1 foot, as in the case
ces, so that the intensities may be obtained in terms of lbs. per
r this reason the dimensions in the following calculations are

ng farther, the section, Fig. 6, must be noticed. It will be seen
kness of the voussoir is 22 inches, but that several of the ribs
wn 2½ inches to receive planking. The effective thickness of
efore 19½ inches. Adding up the vertical depths of the ribs,

22 inches thick and 19½ inches thick, and multiplying the results by their respective thicknesses, the effective sectional area of the voussoir is obtained, viz., 154 inches × 19½ inches = 3,003 square inches; and 107 inches × 22 inches = 2,354 square inches; A = the effective sectional area of the voussoir = 5,357 square inches.

The top rib of all is left out of the calculation. Its only use is as a stiffening-piece, and to carry the gangway.

Turning to the connecting pieces, it will be found that their total thickness is 22 inches. Of this, however, 4 inches will be merely filling timber, and will not add to the strength of the gate. The remaining 18 inches of solid beams must therefore be taken as the effective thickness. The sum of the vertical depths of the connecting pieces = 114 inches; and if a = the sectional area of the connecting pieces; a = 114 inches × 18 inches = 2,052 square inches.

Then F = 2,179,074 lbs.; A = 5,357 square inches; a = 2,052 square inches; from which $\frac{F}{A}$ = 407 lbs. per square inch; $\frac{F}{a}$ = 1062 lbs. per square inch.

As there are a certain number of ribs 22 inches thick, and the remainder 19½ inches thick, it will be necessary to find the intensities of stress for both thicknesses.

Draw Fig 7 (see next page), an enlarged plan of part of the gate at g g¹, and in this case take the voussoir as being the full thickness, viz., 22 inches, so that g will be on the water-line of the back of the gate. Bisect g g¹ in O, and draw X O X¹ perpendicular to g g¹. Mark the point n, in which the arc A n B, Fig. 5, cuts the joint g g¹, and also mark the point n¹, in which the arc A n¹ f cuts g g¹. Then will M^t = F × n O; and if M_1^t = the bending moment due to the nipping of the mitre posts at f, M_1^t = F × n¹ O.

Continue the line g g¹ to g″ on the outer edge of the connecting piece, and make $g^1\ g^1$ equal to the thickness of the filling timber, so that g^1 g″ is the effective thickness of the connecting piece = 18 inches.

Bisect g^1 g″ in O¹, and draw a g v_2, a¹ g¹, g^1 w_2, Y O¹ Y¹, and a″ g″, all parallel to X O X¹.

Make O X = $\frac{F}{A}$ = 407 (to any scale, say 800 lbs. to 1 inch); and draw a X a¹ parallel to g g¹. Also make g″ a″ = $\frac{F}{a}$ = 1,062 (to the same scale as O X), and join O¹ a″. Draw the lines N M t, O M, and the curve t t¹ t″ in the manner described.

Now since n lies between N and O, draw n m parallel to X O X¹, and m v¹ parallel to g g¹.

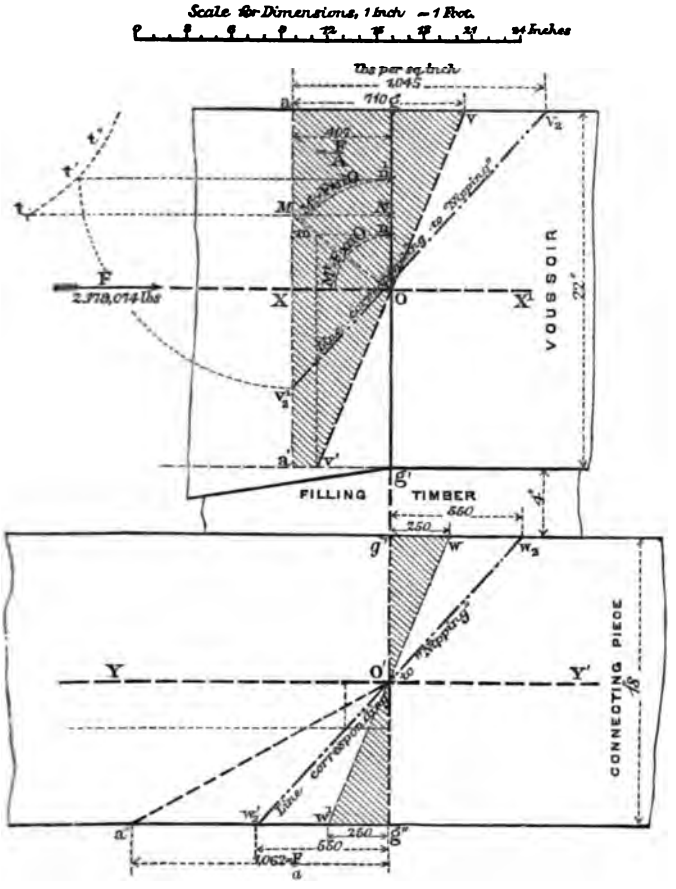
Through v¹ and O draw v O v¹, cutting a g in v. Also through O¹ draw w O¹ w¹ parallel to v O v¹, cutting g^1 w_2 in w, and a″ g″ in w¹. Then will the lines v O v¹ and w O¹ w¹ mark the intensity of stress at any point on the line g g″.

For instance, the maximum intensity of stress is proportional to the length of the line a v; and if this is measured with the same scale as that used to measure O X, it will be found that a v measures 710; that is, 710 lbs. per square inch is the maximum intensity of stress on the large ribs under the assumed conditions of perfect fitting.

Similarly, g^1 w = g″ w¹, represents the maximum intensity on the connecting pieces, and this measures 250 = 250 lbs. per square inch.

If nipping occurs at the inner, or water side, of the mitre-post, n will be moved to n¹, thus increasing the bending moment. The lines v_2 v_2^1 and w_2 w_2^1, corresponding to this position of n¹, can be easily found in the manner described. The maximum intensity on the large ribs due to nipping at f is therefore repre-

FIG. 7.

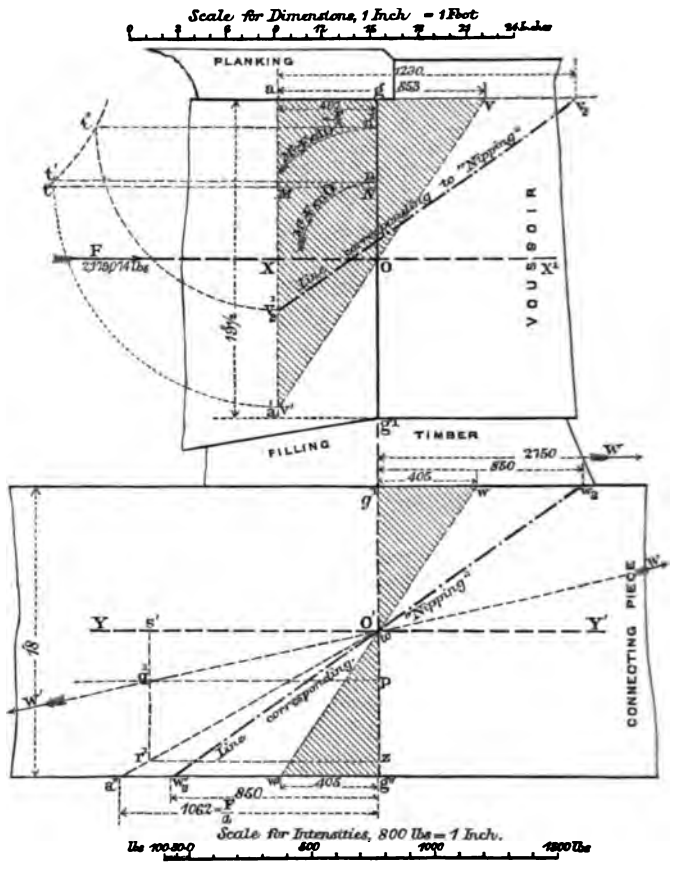


Large Ribs.

nted by a v_2, and this measures 1,045, that is, 1,045 lbs. per square inch. The aximum intensity on the connecting pieces, corresponding to the large ribs, and e to nipping at f, is represented by $g^1 w_2 = g'' w_2^1$, and this is equal to 550 lbs. er square inch.

The diagram Fig. 8 corresponds to the reduced ribs, and is obtained in a similar anner, the only difference being that g is taken at the inside of the planking stead of at the water line; $g g^1$ being now 19½ inches, instead of 22 inches. he diagram shows that the maximum intensities in the case of the smaller ribs e, when the gate is in a normal condition, maximum intensity of stress on ribs

FIG. 8.



Small Ribs.

= 853 lbs. per square inch; maximum intensity of connecting pieces = 405 lbs. per square inch.

When there is an extreme condition of nipping, the maximum intensity of stress on the ribs = 1,230 lbs. per square inch; and in the connecting pieces = 850 lbs. per square inch.

The nipping at f^1, or the outer side of the mitre-post, need not be considered, as it will diminish the bending moment, and so reduce the maximum intensities.

There remains the case of defective jointing, and the consequent possibility of the whole bending moment being borne by the connecting pieces.

Make $O^1p = \frac{1}{3} g^1 g''$, and draw $p q^1$ parallel to $Y O^1 Y^1$. Make $O^1 z = n^1 0$, and draw $z r^1$ parallel to $Y O^1 Y^1$, cutting $O^1 a''$ in r^1. Draw $r^1 q^1 s^1$ parallel to $g^1 g''$, cutting $p q^1$ in q^1. Through O^1 and q^1 draw the straight line $W O^1 q^1 W^1$, cutting $g^1 w_2$ in W, and $a'' g''$ in W^1. Then will this line $W W^1$ mark the intensities on the connecting pieces due to the bending moment = $F \times n^1 0$. That

y, it will mark the intensities due to a bending moment, equal to the ending moment, when the gate is under the unfavourable condition of

represents the maximum intensity of stress (= 2,750 lbs. per square inch) onnecting pieces under such an extreme condition.

Summary of the Maximum Intensities of Stress.[1]

r the normal condition, or perfect fitting, the maximum intensity on the bs is 710 lbs., on the small ribs 853 lbs., and on the connecting pieces ., per square inch.

the mitre-posts nipping on the inner (dock) side, the maximum intensity large ribs is 1,045 lbs., on the small ribs 1,230 lbs., and on the connecting 350 lbs., per square inch.

. imperfect jointing, the whole bending moment being on the connecting the maximum intensity on the large ribs is 407 lbs., on the small ribs , and on the connecting pieces 2,750 lbs., per square inch.

Strength of Greenheart.

. numerous careful experiments on the strength of rectangular beams nheart timber subject to a transverse stress, it has been found that $\frac{d^2 c}{l}$, when W = breaking weight in lbs. applied at the centre of the beam, adth and d = depth of the beam in inches, l = length between the s in feet, c = a constant = 1,079.

e length between the supports is taken in inches, and the formula altered : $\frac{b\,d^2\,C}{L}$, where L = length in inches, then C = constant = 1,079 × 12 48.

= the bending moment at the centre, I = maximum intensity of stress per square inch, $M^1 = \frac{W\,L}{4} = \frac{b\,d^2\,C}{4} = \frac{2}{3} I \times \frac{b\,d^2}{4}$; therefore $I = \frac{3}{2} C = \frac{948}{\quad} =$ 19,422 lbs. per square inch.

maximum intensity of stress at the breaking point, as deduced from the ormula, is therefore I = 19,422 lbs. per square inch.

is probably not quite true for the breaking stress; but if the argument be from it back to a load giving stresses well within the limits of elasticity, -tenth of the breaking load, then it will be practically correct to say that load equal to one-tenth of the breaking load the maximum intensity of equal to $\frac{19{,}422}{10} = 1{,}942$ lbs. per square inch.

e-tenth of the breaking load is considered a safe working load on green- eams subject to a transverse stress, then 1,942 lbs. per square inch may

---

[1] summary the effect of deformation under pressure has been neglected. If the improper ings suggested on page 180 be assumed, n^1 must be moved to a point ¾ inch farther from t shown in Fig. 8; and this will give, for small ribs, with mitre-posts nipping at the , 1,380 lbs. and 1,030 lbs. per square inch, as the maximum intensities, on the voussoir ting pieces respectively, instead of 1,230 lbs. and 850 lbs., as quoted in the summary.

be considered a safe working limit for the maximum intensity of stress due to a bending moment on similar beams.

The maximum intensity of stress on the connecting pieces of the gate just examined is, under exceptional circumstances, = 2,750 lbs. per square inch $= \frac{19,422}{7}$ nearly; and therefore equal to the maximum intensity of stress that would be caused by a load one-seventh of the breaking load.

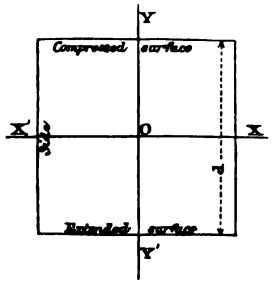
APPENDIX D.

Deflection of Wooden Beams of Uniform Rectangular Section Throughout their Length.

If an elastic beam is supported at both ends, and then loaded in a direction transverse to its axis, the form of the beam will be changed, and every point therein, except those points immediately over the supports, will assume a new position after traversing a space, at right angles to the axis, proportional to the extent and manner of loading. The greatest distance so traversed by any portion of the beam will be considered as the measure of its deflection, and will be denoted by the symbol V. If the load is applied symmetrically with regard to the centre of the beam, the position of greatest deflection will be at the centre. The scope of the present investigation will only include cases in which the load is thus applied, so that it will be sufficient to consider the stresses, and changes of form, which occur in one half of the beam; and to save further definition it must, unless otherwise stated, be assumed that if one half of a beam is said to be loaded in a certain manner, the other half is also loaded in a similar manner; and that where the symbol V is used, it represents the change of position at the centre of the beam, be it deflection or camber.

The effect of loading a beam in a direction transverse to its axis (the beam being supported at the ends only) is to subject it to a series of bending moments throughout its entire length, the magnitude and distribution of those moments depending on the magnitude and distribution of the load. Any transverse load, wherever applied, will cause a bending moment on every cross section of the beam. The axis of the beam is the line formed by the centres of all the cross sections. It will be assumed that the load, the supports, and all the bending moments, act in a plane, which may be termed the "plane of action," containing the axis, and parallel to two sides of the beam.

Fig. 9.



If a diagram be drawn representing a cross section of the beam (Fig. 9), the point O at the centre of the figure will represent the axis; also if a line, Y O Y', be drawn through O parallel to the two sides of the beam, the line Y O Y' will represent the "plane of action."

If at any cross section the beam is subjected to the action of a bending moment, it will at that section bend through a certain angle in the plane of action, such bending, or angular motion, taking place round an axis perpendicular to that plane, and situated within the beam. The effect of the angular motion will be, to compress all the fibres on one side of this axis, and to extend all those on the

other side, the magnitude of such compression or extension, and consequently the intensity of stress on any fibre, varying directly as the distance from the said axis; whilst on the line of the axis itself, tension will merge into compression, and the fibres coinciding with the axis will be in a neutral state of no stress, so far as the bending moment is concerned; hence this line may be termed the neutral axis of the cross section.

It is obvious that the stresses of compression and tension caused by a bending moment at any cross section must be equal to each other, otherwise there would be a tendency to move the whole in one direction; and since the beam is rectangular, and its elasticity supposed to be uniform throughout, the areas of compression and tension on either side of the neutral axis must be equal to each other; that is to say, the neutral axis must divide the cross section into two equal parts. Therefore, if in Fig. 9 the line X O X^1 be drawn perpendicular to Y O Y^1, passing through O, the axis of the beam, then the line X O X^1 will represent the neutral axis of the cross section.

And because the intensities of compressive and tensile stresses increase as the distance from the neutral axis, therefore at any cross section the maximum intensities of stresses due to a bending moment will be at the surfaces of the beam parallel to the neutral axis, and the intensity of stress at each of these surfaces will be the same, but the stresses will be of opposite character, one being tension, the other compression.

The plane containing the neutral axes of all the cross sections may be termed the plane of neutral axes, and it will be convenient to call the surfaces of the beam parallel to this plane the "compressed" and "extended" surfaces respectively, and the surfaces perpendicular thereto the "sides" of the beam.

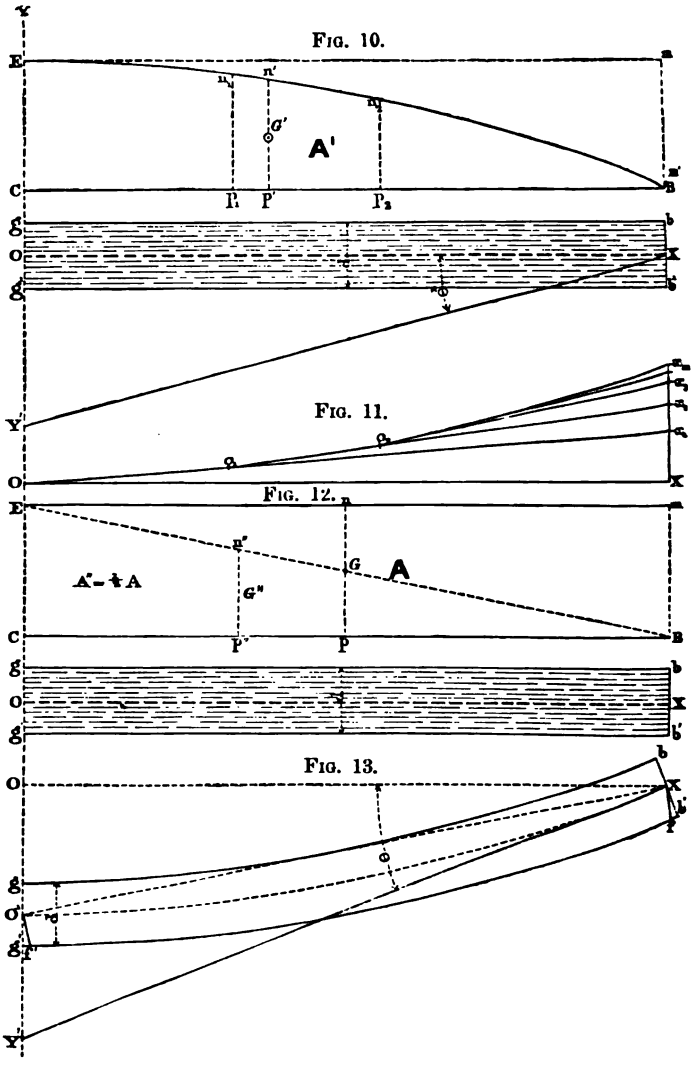
If at any cross section under the action of a bending moment i = the intensity of stress at the extended or compressed surface due to the bending moment; m^t = the bending moment, A = the sectional area of the beam, and d = the thickness of the same (from the compressed to the extended surface); then $i = \frac{6\,m^t}{A\,d}$; and since A × d is the same throughout, i is in all cases proportional to the bending moment m^t.

Also because the material is elastic, the elongation of the fibres at the extended surface, and the shortening of those at the compressed surface, will each be proportional to $\frac{i}{E}$, and therefore to m^t, if E = coefficient of elasticity.

The angle through which the beam bends is obviously proportional to the elongation of the extended surface, and therefore to m^t.

If a side elevation of one half of the beam be drawn as in Fig 10, in which O is the centre of the beam, O X the line representing the axis, g b the compressed surface, g^1 b^1 the extended surface, and Y O Y^1 a line through O, perpendicular to O X; and from the point C, in the line Y O Y^1, a line C B be drawn parallel to, and of the same length as, O X; then by drawing a series of lines, or ordinates, perpendicular to C B, and making the lengths of these ordinates proportional to the magnitude of the bending moments at the cross sections corresponding thereto, the extremities of the ordinates will form a curve, commonly called the curve of bending moments, represented in the diagram by the line E n^1 m^1.

And because at any cross section, the intensity of stress on the fibres of the extended surface, the elongation of those fibres, and the angle through which the beam is bent are each proportional to the bending moment, they are also proportional to the ordinate of the curve E n^1 m^1 at that section. Consequently, the sum of all the bending moments, the sum of all the elongations of the extended



surface, and the sum of all the angles through which the beam is bent, are each proportional to the area of the figure C E n' m' B.

Since every cross section of the beam is subjected to the action of a bending moment, there will be a proportionate amount of angular motion at every point along the axis, which will assume the form of a curve. The tangent to this curve, at the extremity of the beam, must form an angle with the original line of axis equal to the sum of all the angles through which the beam is bent at the various cross sections, and therefore proportional to the area of the figure C E n' m' B. If

$\mathbf{X}\,Y^1$ is the tangent to the curve at the end of the beam, and the angle $O\,X\,Y^1 = \theta^1$, then θ^1 is proportional to the area of the figure $C\,E\,n^1\,m^1\,B$.

If at any cross section r = the radius of curvature of the axis, it is easy to show that $r = \frac{E}{i} \times \frac{d}{2}$; so that r is inversely proportionate to i, and therefore to m^1.

In Fig. 11, let O X represent the axis of a beam similar in all respects to that in Fig. 10. Now if at O the beam is bent through an angle $X\,Q\,x_1$, the space $X\,x_1$, traversed by the extremity of the beam, is clearly proportional to the angle $X\,O\,x_1$ multiplied by the length $O\,x_1$, provided $X\,O\,x_1$ is a very small angle; so that if the angle $X\,O\,x_1$ is proportional to the ordinate C E in Fig. 10, the space $X\,x_1$ is proportional to $C\,E \times C\,B$. Also if at the point o_1 the beam is bent through a further angle $x_1\,o_1\,x_2$, the corresponding space $x_1\,x_2$, traversed by the end of the beam, will be proportional to the angle $x_1\,o_1\,x_2$ multiplied by $o_1\,x_2$, and therefore proportional to $p_1\,n_1 \times p_1\,B$, in Fig. 10, if p_1 is the point on C B corresponding to o_1 in Fig. 11. Similarly for the point o_2, corresponding to p_2, the space $x_2\,x_3$ is proportional to $p_2\,n_2 \times p_2\,B$.

The whole space $X\,x_m$, traversed by the end of the beam, is therefore proportional to $(C\,E \times C\,B + p_1n_1 \times p_1\,B + p_2n_2 \times p_2\,B + \ldots + p_m\,n_m \times p_m\,B)$.

As at every point the beam in Fig. 10 is bent through an angle extremely small, but proportional to the ordinate at that point, the expression above is obviously equal to the area of the figure $C\,E\,n^1\,m^1\,B \times p^1\,B$, if $p^1\,n^1$ is the ordinate passing through G^1, the centre of gravity of the figure $C\,E\,n^1\,m^1\,B$.

So that if A^1 = the area of the figure, $C\,E\,n^1\,m^1\,B$, and $V^1 = X\,x_m$, then $V^1 = f \times (A^1 \times p^1\,B)$.

It has been shown that θ^1 is proportional to the area of the figure $C\,E\,n^1\,m^1\,B$; hence $\theta^1 = g \times A^1$, f and g being functions the value of which need not be inquired into.

Now take the case of a beam such as that outlined in Fig. 12, the length, breadth, and thickness of which are the same as those of the beam in Fig. 10; and suppose it to be loaded in such a manner that the bending moments are of equal magnitude throughout, and that the bending moment at any cross section is equal to the bending moment at the centre of the beam in Fig. 10.

If in Fig. 12 the ordinates C E and B m be each made equal to the ordinate C E in Fig. 10, and E m be drawn parallel to C B, then E m will be the curve of bending moments under the supposed condition of loading.

Let Fig. 13 show the form of the beam after deflection. The radius of curvature at any cross section is equal to $r = \frac{E}{i} \times \frac{d}{2}$, and since i is uniform throughout, r will be the same at every point of the axis, which will take the form of the arc of a circle, the radius of which may be denoted by $R = \frac{E}{i} \times \frac{d}{2}$.

The centre of the axis is now at O^1, so that if O X was the original line of axis, the deflection = $O\,O^1 = V$.

Draw the chord $O^1\,X$, and through O^1 and X draw $O^1\,f^1$ and X f, perpendicular to $O^1\,X$. Then if ϵ = the total elongation of the extended side, $\frac{\epsilon}{2} = \frac{d}{2} \times \tan g^1\,O^1\,f^1$; $\epsilon = d \times \tan O\,X\,O^1$, $= d \times \frac{O\,O^1}{O\,X}$.

Therefore if $L = O\,X$ = half the length of the beam, $\epsilon = \frac{V\,d}{L}$ (1), the angle $O\,X\,O^1$ being so small that there is no appreciable difference of length between $O\,X$ and $O^1\,X$. But $\epsilon = \frac{i}{E} \times L$ (2), and $i = \frac{6\,M^1}{A.d}$ (3).

From (1), (2), and (3), $V = \frac{6 M^1 L^2}{E A d^2}$ . . . . . (a)

If X Y¹ is the tangent to the axis at X; θ = angle O X Y¹; O Y¹ = $L \tan \theta$,

$= 2 V, = \frac{12 M^1 L^2}{E A d^2}$ . . . . . (b)

It has already been shown that if A = the area of the figure C E m B, Fig. 12; G the centre of gravity of the same; p n the ordinate passing through G; then $V = f \times (A \times p B)$, $\theta = g \times A$.

Again, suppose the same beam to be loaded in such a manner that the bending moment at the centre is the same as before = M^1; but the curve of bending moments is now a parabola, as in Fig. 10, m¹ coinciding with B. C E in Fig. 10 is therefore = C E in Fig. 12, C B being the same in both cases. Therefore $A^1 = \frac{2}{3} A$, $p^1 B = \frac{5}{4} p B$; but $V^1 = f \times (A^1 \times p^1 B) = \frac{2}{3} \times \frac{5}{4} f \times (A \times p B)$.

Therefore $V^1 = \frac{5}{6} V = \frac{5 M^1 L^2}{E A d^2}$ c

Also $\theta^1 = g \times A^1 = g \times \frac{2}{3} A = \frac{2}{3} \theta$.

Therefore $L \tan \theta^1 = \frac{2}{3} L \tan \theta = \frac{4}{3} V = \frac{8 M^1 L^2}{E A d^2}$ . . . . . (d)

Similarly, if the curve of bending moments is the straight line E B, Fig. 12, and A" = the area of the triangle C E B; G'' the centre of gravity of the same; p"n" the ordinate passing through G''; V" the corresponding deflection.

Therefore $A'' = \frac{1}{2} A$, $p''B = \frac{4}{3} p B$; so that $V'' = \frac{1}{2} \times \frac{4}{3} V = \frac{4 M^1 L^2}{E A d^2}$. (e)

And $L \tan \theta'' = \frac{1}{2} L \tan \theta = V = \frac{6 M^1 L^2}{E A d^2}$ . . . . . (f)

But the parabola, as in Fig. 10, is the curve of bending moments for a beam uniformly loaded throughout its length; and the straight line, as E B in Fig. 12, which, with the base and ordinate at the centre, forms a triangle having its apex at the centre of the beam, is the curve of bending moments for a beam loaded at the centre only.

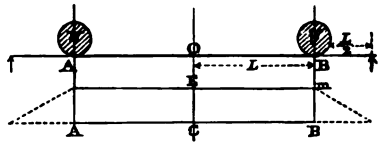
Similarly, if for any given distribution of load the curve of bending moments be drawn, the corresponding values of V and $L \tan \theta$ can be obtained in the manner above indicated.

The following are a few examples giving the values of V and $L \tan \theta$ for different methods of distributing the load. In each case the upper figure shows the distribution of load; and the lower, the curve of bending moments.

V = deflection at the centre; $L \tan \theta$ = distance corresponding to O Y¹ in Fig. 13; M^1 = bending moment at the centre.

Uniform bending Moments.

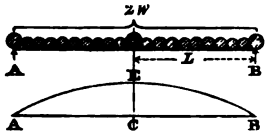
FIG. 14.



$M^1 = \frac{w L}{2}$, $V = \frac{6 M^1 L^2}{E A d^2}$, $L \tan \theta = 2 V = \frac{12 M^1 L^2}{E A d^2}$.

Load uniformly distributed.

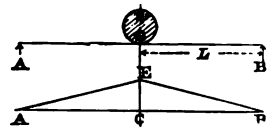
FIG. 15.



$$M^1 = \frac{w L}{2}, V = \frac{5 M^1 L^2}{E A d^2}, L \tan \Theta = \frac{8 M^1 L^2}{E A d^2}.$$

Load at Centre of Beam.

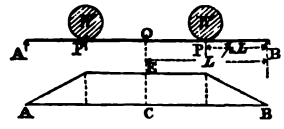
FIG. 16.



$$M^1 = \frac{w L}{2}, V = \frac{4 M^1 L^2}{E A d^2}, L \tan \Theta = \frac{6 M^1 L^2}{E A d^2}.$$

Two equal Weights placed at points, one-fourth of the whole length from ends of Beam.

FIG. 17.

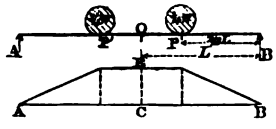


$$M^1 = \frac{w L}{2}, V = \frac{33 M^1 L^2}{6 E A d^2}, L \tan \Theta = \frac{9 M^1 L^2}{E A d^2}.$$

If v = the deflection at p and p¹, the points under weights, $v = \frac{33 M^1 L^2}{6 E A d^2} - \frac{M^1 L^2}{A d^2} = \frac{4 M^1 L^2}{E A d^2}$.

Two equal Weights placed at points one-third of the whole Length from ends of Beam.

FIG. 18.



$$M^1 = \frac{w L}{2}, V = \frac{46 M^1 L^2}{9 E A d^2}, L \tan \Theta = \frac{8 M^1 L^2}{E A d^2}.$$

If v = deflection at p and p¹, $v = \frac{40 M^1 L^2}{9 E A d^2}$.

If two straight beams, A C and B C, of uniform rectangular section, of equal length, and generally similar in every respect, are placed end to end, in one straight line, in the same plane of action, the adjacent ends resting on one common support, C, and the remote ends on two other supports, A and B; then if a load is uniformly distributed throughout the entire length of both beams from A to B, the effect will be, that each beam will deflect independently of the other; their axes will take the form of certain curves, and if C coincides with the straight line joining A and B, the tangents to those curves at the ends resting on C will form an angle with each other, as y O y¹ in Fig. 19. Now, if without disturbing the

Fig. 19.

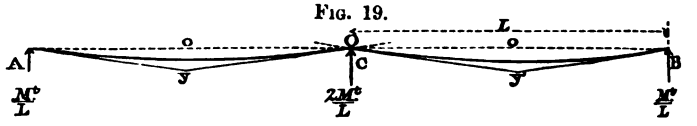


Fig. 20.

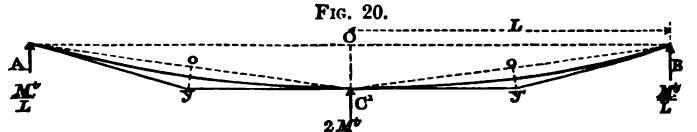
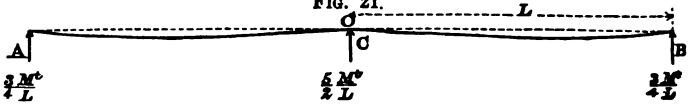


Fig. 21.



conditions of loading, C be gradually withdrawn from the load, it is evident that at some definite distance below the line A B it will arrive at a point where the tangents to the axes of the beams will coincide, and form one straight line parallel to A B, as y C¹ y¹ in Fig. 20. If C¹ is the position of C, when the tangents y C¹, y¹ C¹ are parallel to A B, draw the straight line C¹ B, and perpendicular thereto draw o y¹, bisecting C¹ B in o.

Let L = the length of one span = A C = B C, $l = \frac{L}{2}$.

Let m^t = the bending moment at the centre of each span, Θ = the angle between the tangent and the chord of the axis as before = $\angle$ B C¹ y¹; then $o y^1 = l \tan \Theta = \frac{8 m^t l^2}{E A d^2}$.

But because O B C¹ and B C¹ y¹ are very small angles, $O C^1 = 2 o y^1 = \frac{16 m^t l^2}{E A d^2}$

If $M^t = 4 m^t$, and O C¹ = v; $v = \frac{M^t L^2}{E A d^2}$.

Also if w = the load per unit of length, therefore $w L$ = the load on each beam, $m^t = \frac{w L^2}{8}$, $M^t = \frac{w L^2}{2}$.

The loads on the supports will be $A = \frac{w L}{2} = \frac{M^t}{L}$, $B = \frac{w L}{2_j} = \frac{M^t}{L}$, $C = wL = \frac{2 M^t}{L}$.

It has been supposed that the two spans have been covered by two separate beams, A C and B C. By lowering C through a distance = V, the ends of the

beams resting on C have been brought into such a position that the tangents to the axes at C^1 coincide with one another, and form parts of one straight line; and, as there can be no bending moment at C^1, it is obvious that the condition of things will be in no way affected if the ends of the beams at C^1 are joined to one another, so that instead of two, the whole is one continuous beam from A to B.

It follows, therefore, that when a beam of uniform rectangular section is continuous over two equal spans, and carries a uniformly distributed load, the condition that there shall be no transverse strain on the beam over the centre support is fulfilled when the centre is lower than the ends by a distance $= \frac{M^1 L^2}{E A d^2}$, M^1 being the bending moment that would occur at the centre of the beam, supposing there was no centre support, and that the whole was one span from end to end. Under the above conditions the loads on the supports are, at the ends $= \frac{w L}{2} = \frac{M^1}{L}$; at the centre $= w L = \frac{2 M^1}{L}$.

Now, suppose that the beam is continuous from A to B, and that starting with C in the position of C^1, an additional force $= 2x$ be applied at C^1, acting against the load; the effect will be that C will be again raised until the end supports are each relieved of a load $= x$, and the beam will come to rest when the loads on the supports are, at each end $= \frac{M^1}{L} - x$, and at the centre $= \frac{2 M^1}{L} + 2x$.

The force $2x$ applied at the centre in a direction contrary to the load, will cause an inverse bending moment at the centre $= -m^1$, and $-m^1 = -xL$.

The force $2x$ will also cause a deflection in an inverse direction; and this inverse deflection being due to a force applied at the centre, must be, as already shown, $-V = -\frac{4 m^1 L^2}{E A d^2}$.

If the force $2x$ is that which, added to $2\frac{M^1}{L}$, will raise C from its position at C^1, until it again coincides with the line A B, then $V = v$, and $\frac{4 m^1 L^2}{E A d^2} = \frac{M^1 L^2}{E A d^2}$.

Therefore $m^1 = \frac{M^1}{4}$, but $x L = m^1$, and $M^1 = \frac{w L^2}{2}$, so that $x L = \frac{w L^2}{8}$, $x = \frac{w L}{8}$.

The loads on the supports are, at each end $= \frac{M^1}{L} - x = \frac{w L}{2} - \frac{w L}{8} = \frac{3}{8} w L$; at the centre $= 2\frac{M^1}{L} + 2x = w L + \frac{w L}{4} = \frac{5}{4} w L$.

Therefore when a beam of uniform rectangular section is continuous over two equal spans, and carries a uniformly distributed load, if the centre support is in the same straight line as the two end supports there will be an inverse bending moment over the centre support $= \frac{M^1}{4}$, and the loads on the supports will be, at each end $= \frac{3}{8} w L = \frac{3}{4}\frac{M^1}{L}$, and at the centre $= \frac{5}{4} w L = \frac{5}{2}\frac{M^1}{L}$, M^1 being the bending moment that would occur at the centre of the beam, supposing that there was no centre support, and that the whole was one span from end to end.

The curves of bending moments and points of contrary flexure can easily be deduced from the foregoing investigation.

SECT. II.—OTHER SELECTED PAPERS.

No. 1,626.—"On the Strength and Elasticity of Materials."[1] By WILLIAM JAMES MILLAR, Civil Engineer, Secretary to the Institution of Engineers and Shipbuilders in Scotland.

THE object of the Author is briefly to describe some experiments upon the strength and elasticity of materials. During the course of his practice he has made numerous tests of cast-iron bars, the results of which are given in

TABLE I.

Dimensions of Bars.			Number of Tests.	Average Ultimate Strength.	Average Ultimate Deflection.	Average Modulus of Rupture.	Remarks.
Span.	Breadth.	Depth.					
Inches.	Inches.	Inches.	Bars.	Lbs.	Inch.	Lbs. per Square inch	
36	1	2	1,344	3,740	·400	50,490	The bars were loaded at the centre.
36	1	1	50	801	·583	43,254	
36	2	1	1	1,763	·843	47,601	
..	..	..	Links. 66	21,122	..	..	

From the above results the following constants and rules have been determined:

$$W = \frac{25 \times b\,d^2}{S}\,;\quad D = \frac{W \times S^3}{b\,d^3} \cdot 0036\,;\quad T = \frac{\cdot 44 \times W \times S}{b\,d^2}\,;\quad W = \frac{T \times b\,d^2}{\cdot 44 \times S},$$

when W = ultimate load in cwt. at the centre of the bar; S = span in feet; b = breadth in inches; d = depth in inches; D = deflection in inches; and T = tenacity in tons per square inch.

It was found that when the bar broke at, or close to, the centre, the fracture was straight; but when fracture occurred at points removed from the centre, the form was curved: hence the form of fracture invariably shows the position of fracture. The Author

[1] Abstract by the Author of an Original Communication, which is accompanied by several diagrams.

so proved by experiment that this law applies to bars of glass, and sealing-wax. These curved fractures all pointed ls the point of application of the load, the curve increasing ıe distance of fracture from the centre of the bar. In no as a wedge-shaped piece forced out of the compressed side of ır: the fractured parts always fitted together. Flakey or fractures with a purplish grey colour indicated strength. mooth surfaces, crumbling to the touch, indicated weakness; ɪling metallic look indicated soft iron. The breaking of the surface, or skin, did not materially affect the strength.

ɔn bars had been subjected to a high load, it was found in cases that, on a second application, they broke below the pplied load. Vibration, obtained by tapping the bar when , had also the effect of causing rupture.

e exceptionally strong bars showed a decrease of deflection ncrease of load, as will be seen by

TABLE II.

ge of fourteen bars unbroken . Loads, lbs.	3,360	3,920	4,480
Deflection[1] . . . . . Inch	·327	·317	·313
experiment . . . . . Loads, lbs.	3,360	3,920	4,480
Deflection . . . . . Inch	·380	·370	·350
Set . . . . . „	·008	·002	·000

eriments to determine the law of set showed that, at high the set decreased for additional loads. There was also a se of set for repeated applications of the same load; but starting with small loads, and gradually rising until fracture lace, the set appeared to increase, then remain steady, and ards decrease. Some of these results are shown in

TABLE III.

ge of ten bars unbroken . . Loads, lbs.	3,360	3,920	4,480
Deflection . . . . . Inch	·341	·367	·388
Set . . . . . „	·026	·014	·008

deflections mentioned in the tables are those for the corresponding The deflection and set for each experiment being noted, a re-adjustment eflection circle to zero was made, and the experiment repeated.

TABLE IV.

Load applied, 2,800 lbs.	Bar No. 1.		Bar No. 2.		Bar No. 3.		Bar No. 4.	
	Deflection.	Set.	Deflection.	Set.	Deflection.	Set.	Deflection.	Set.
	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1st application of load	·302	·021	·336	·020	·290	·012	·298	·015
2nd „ „	·282	·003	·317	·005	·290	·005	·296	·002
3rd „ „	·279	·001	·310	·001	·286	·003	·285	·002
4th „ „	·278	·000	·312	·000	·282	·000	·281	·000
5th „ „	·276	·002	·313	·000	..	..	..	..
6th „ „	·273	·001	·315	·000	..	..	..	..
	Finally broke about 3,500 lbs. Deflection, ·403		Finally broke at 4,270 lbs. Deflection, ·518		Finally broke at 4,330 lbs. Deflection, ·455		Finally broke at 3,760 lbs. Deflection, ·395	

Often when near the breaking point a slight increase of deflection was observed to take place suddenly. From various observations this change appeared to occur at loads of about 97 per cent. of the ultimate strength.

In experiments to determine the relative strengths of hot- and dull-run metal, the bars were cast from the same metal, the first being cast as hot as possible, and the others from metal which had been allowed to cool until it would only just flow into the mould, with the result shown by

TABLE V.

——	Hot Metal.		Dull Metal.	
	Ultimate Strength.	Ultimate Deflection.	Ultimate Strength.	Ultimate Deflection.
	Lbs.	Inch.	Lbs.	Inch.
Average of ten bars .	3,524	·402	3,619	·371

It will be observed that the dull-run metal gives the highest breaking strength, but the deflection is less than with the hot-run metal.

From experiments upon the cooling of bars, it was found that bars cooled in the mould gave higher results than those cooled in the air; thus—

The average of nine bars cooled in the mould was 4,206 lbs. with a deflection of 0·404 inch.

The average of ten bars cooled in the air was 4,009 lbs., with deflection of 0·396 inch.

So far as the Author has been able to determine, the action of severe frost on bars does not affect their strength.

The results of experiments, made at the instance of Mr. David Kirkwan, M. Inst. C.E., and recorded by the Author, on bars of forged and rolled iron, subjected to bending stress in a similar manner to the cast-iron bars, but with the application of the same load, are given in

TABLE VI.

Load applied, 37 cwt. Forged Bar.	Deflection.	Set.	Load applied, 37 cwt. Rolled Bar.	Deflection.	Set.
Span 36 inches; breadth $1\frac{1}{16}$ inch; depth 2 inches.	Inch.	Inch.	Span 36 inches; breadth 1 inch; depth 2 inches.	Inch.	Inch.
1st application of load .	·230	·031	1st application of load .	·700 rising to ·870	·535
2nd " " .	·200	..			
3rd " " .	·180	·062			

These experiments were repeated, with increasing loads, when the results arrived at are shown in

TABLE VII.

Forged bar . . Cwt.	32	34	35	37	Left in machine at 37 cwt. for seventeen hours.
Loads . . Lbs.	3,584	3,808	3,920	4,144	
Deflection . Inch	·180	·175	·180	·192	Deflection ·180, and set ·093 inch.
Set . . . "	None	..	..	None	
Rolled bar . . Cwt.	26	26	28	30	32
Loads . . Lbs.	2,912	2,912	3,136	3,360	3,584
Deflection . Inch	·150	·150	·160	·170	·190, rising to ·235 inch.
Set . . . "	None	None	None	..	Set ·062 inch.

The critical points in these bars appear to lie about 36 and 30 cwt. Taking these loads as the limit of elasticity, the modulus of longitudinal strength or tenacity would be, $f = \frac{6 \times W \times S}{4 \times b d^2}$, where W = load in lbs., S = span in inches, b and d being the

breadth and depth in inches. Substituting the values as given for the above bars, then—

$$\text{in the forged bar, } f = \frac{6 \times 3{,}920 \times 36}{4 \times 1\frac{7}{16} \times 2^2} = 49{,}807 \text{ lbs.},$$

and

$$\text{in the rolled bar, } f = \frac{6 \times 3{,}360 \times 36}{4 \times 1 \times 2^2} = 45{,}360 \text{ lbs.}$$

Taking the formula, $E = \frac{W \times S^3}{4 D b d^3}$, as the modulus of elasticity, then, when W = 3,920 lbs.,

$$\text{for the forged bar, } E = \frac{3{,}920 \times 36^3}{4 \times \cdot 180 \times 1\frac{7}{16} \times 8} = 29{,}880{,}000 \text{ lbs.}$$

and

$$\text{for the rolled bar, } E = \frac{3{,}360 \times 36^3}{4 \times \cdot 170 \times 1 \times 8} = 28{,}800{,}000 \text{ lbs.}$$

In the above formula D is the deflection in inches.

If the cast-iron bars be taken at loads where set disappears, and the whole deflection becomes elastic, the modulus of elasticity will vary from 14,500,000 to 18,600,000 lbs.

The Author inclines to the belief that the so-called "set," observed in cast iron bars, is really due to the relief of the particles from strain produced in cooling, and is not similar to the permanent set observed in wrought iron and steel. From the results of the experiments on the cast-iron bars the elastic deflection appears to vary proportionally with the load.

No. 1,621.—"Description of Machinery for the Production and Transmission of Motion, in the large Factories of East Lancashire and West Yorkshire." By GEORGE WILLIAM SUTCLIFFE, Assoc. M. Inst. C.E.

THOUGH the subject treated in this Paper is, of necessity, more or less familiar to the members of the Institution, it is written in the hope that it may prove of interest to many who are not directly conversant with the district in question.

PRODUCTION OF MOTION.

For the production of motion—commonly called power—steam is employed, to the almost total exclusion of any other agent. Water power is not so abundant in England as it is in some foreign countries; but still there are opportunities for its profitable use, if judiciously supplemented by steam power. So many turbines and water-wheels have failed to give successful results, that water motors have as a rule been condemned, though there are several kinds possessing superior merit. These failures have resulted, mainly, either from ignorance of the laws of hydraulics, or from defective proportions and finish of the machinery. Every square mile of freely drained area of watershed in this district will furnish 0·2 HP. per foot of fall (with very little storage), except during a few weeks in summer, when steam machinery is in its state of maximum efficiency, and steam is less required for heating purposes.

The universal type of steam generator is the Lancashire boiler, having a shell 28 to 30 feet long, by 6 feet 6 inches to 7 feet in diameter, the fore end being attached by outside angle irons, the rear end by inside angle irons, or flanging of the end plate; and two furnace tubes about 2 feet 9 inches in diameter, fixed longitudinally below the water level. In the original arrangement the furnace tubes were separate throughout their whole length. Messrs. W. and J. Galloway, of Knott Mill, Manchester, form the rear ends of furnace tubes into one combustion chamber, with a cross section as shown in Plate 3, Fig. 1. When first adopted the cross section was elliptical. All good boilers are provided, at the rear end of the furnace tubes, or in the combustion chambers,

with water tubes, of which many forms are made, Galloway's being shown in Figs. 1 to 5. These tubes promote circulation of water, and utilise much heat that would otherwise be lost. The section of combustion chamber shown in Fig. 1 allows almost absolute interchangeability of tubes; it is also much more accessible on the lower side than the previously arranged chambers. Various systems of riveting are adopted for the transverse joints of furnace tubes; but the best, in the Author's opinion, is Mr. Adamson's flanged joint (Fig. 6), made by flanging the edges of the adjoining plates outwardly, then inserting an annular thin plate between the two, and passing the rivets through the three pieces, the whole being caulked. This joint allows the expansion and contraction of the tubes to take place with at least as much freedom as any other joint, and is eminently suited for use in the neighbourhood of the fire, while it presents no rivets or double thickness of plates to the direct action of the fire; it also strengthens the tube against collapse caused by external pressure. The longitudinal joints of the tubes are usually single riveted lap joints, breaking joint with each other, but all below the centre horizontal plane of the furnace tube; they are usually about 90° apart in circular tubes. No riveted joint ought to be acted upon by the flame, either by being situated over the fire or in the upper part of the combustion chamber near the furnace; the thickness of metal along a riveted joint being double the ordinary thickness of the tube plates, the difference between the temperatures on the opposite sides of plates along the joints is double the amount elsewhere, so that straining is caused by the unequal expansion. The longitudinal joints of the shell are double-riveted joints, either lapped or outside-strip butt joints. The transverse joints of the shell are single-riveted lap joints, or, in rare cases, they are butt joints.

The relative merits of drilled and punched holes remain an open question. The rivets have little hold in the drilled hole, and, unless the drills are well sharpened, they tend to cause a "burr," which, if not removed, almost prevents the possibility of making a tight joint. Rivet holes are often punched with little care as to accuracy, or with deficient clearance in the die, and because these are weaker, or show leakage, a case is made out against all punched holes. A boiler is supposed to stand much waste from corrosion before becoming unsafe, and as corrosion does not take place inside the joint, there is ultimately a greater thickness of material along the joint than in the body of the plate, even in those cases where actual grooving does not occur. Of course, if the

corrosion is entirely on one side this fact possesses no value; but where corrosion takes place equally on the two sides, the extra remaining thickness along the joint does much to compensate for that removed in making the holes, and in many cases prevents the somewhat greater strength of drilled holes over that of punched holes from possessing any real value. Fig. 7 shows this action.

The end plates are stayed (in addition to the staying effect of the furnace tubes) by two bolts, passing longitudinally through the boiler from end to end, with nuts and cast-iron washers at each end; gusset stays (Figs. 1 to 4) are often added to, or are substituted for, the stay bolts. Four or five gusset stays are in this case provided at each end, some of which are attached to the first ring of the shell, and the others to the second ring. All stays (but more especially the gusset stays) must be arranged to allow of free expansion and contraction of the furnace tubes relatively to the shell.

In the majority of cases the material used is iron. Steel has been often and satisfactorily employed; and with due regard to experience, it may be used slightly thinner under equal conditions, thus offering less resistance to the passage of heat. Great care must, however, be exercised in selecting steel of the proper temper, and in annealing the plates, otherwise there is a risk of cracks forming in the boiler after use, more especially if suddenly or rapidly cooled down.

The furnace is provided with grate bars carried on cast-iron cross pieces. The grate bars are of cast iron, 2 feet to 3 feet long, taper in cross section, with distance pieces cast with each bar at the ends and at the centre of the length. Each bar is cast singly; the bars have been often made in nests of three or four, but without success, chiefly owing to the mass warping. When the grate bars are parallel to the axis of the boiler they can be more easily cleared than when in any other position, but they cannot be perpetually cleared, and the local heating occurs during the intervals. However, no mischief results with single bars during ordinary work, and the pattern appears likely to endure, at least for hand-fired boilers, though the material may be displaced by some other and more durable one. Many other patterns—transverse, zigzag, and with differently-formed apertures for the admission of air—have been introduced, and withdrawn after a brief experience of their disadvantages. These patterns have been devised with a view to increased air admission, but all become filled with cinder.

The production of smoke may be reduced to a small amount by careful stoking. Some firms give a quarterly premium to the stoker for low smoke production; and a mirror is often set outside the boiler-house, so that the stoker may see what quantity of smoke is issuing from the chimney top.

Several systems of mechanical stokers are now largely used, and so far appear tolerably successful when the steam supply is nearly uniform. Some stokers regulate the coal supply by means of indented plates reciprocating across the mouth of the coal hopper, and thus delivering the coal on the dead plate; in this system the bars must be arranged to reciprocate, so as to propel the coal towards the rear of the grate.

Another class of mechanical stoker is provided with a sliding measure, to place the coal in a suitable position for the action of a plunger, which, being propelled by a cam, suddenly throws the coal on the fire. This is not yet completely successful.

Probably the best and most popular system is that in which the coal is withdrawn from the mouth of the hopper by a pair of spiked rollers (occasionally only one), which break up the coal, and drop it on a roller set directly beneath, and provided with measuring recesses. These recesses transfer the crushed coal to a fan or beater, which throws it on the fire, deflecting plates being provided to spread it over the required surface. All mechanical stokers appear more or less incompetent to deal with wet coal, and they are often for this reason inapplicable in cases where they might otherwise be successful. Being driven by the main engine, they are inoperative before the engine is started; it is therefore necessary that means should be provided for allowing the fires to be stoked by hand at such times, also for "banking up," and in cases of casualty.

Each boiler requires provision for the admission of air over the fire, for the thorough combustion of the gases, and for the prevention of smoke when hand fired; this is not so necessary with mechanical stokers, owing to the greater regularity of the fuel supply. Air is usually admitted by means of a perforated door provided with a cover, which is set according to experience and observation, requiring care and discretion to yield good results. Many methods of variable admission—full when first stoked, and afterwards decreasing—have been applied to furnace doors, and to bridges, but with limited success. The usual direction of the flues outside the boiler is such as to allow the gases from the combustion chamber to divide without control, passing along each side of the boiler from rear to front, then to

meet and enter one passage beneath the boiler, and pass from front to rear, and away to the chimney. A damper is provided in some part of the passage to the chimney; this damper usually works up and down, being connected by chains over pulleys to a balance weight in the stokehole. Dampers, however, are sometimes applied on a vertical axis, worked either by a shaft and mitre-wheels, or by a push-rod and lever from the stokehole.

A valve is required to regulate the feed supply; the best is the ordinary screw-down stop valve, with the necessary condition that the valve itself is not collared to the spindle, but is left free to drop, and act as a retaining valve at the same time; otherwise a separate retaining valve becomes necessary. A good position for the feed valve is a few inches below low-water level, on either side of the boiler. The feed pipe should be continued 3 or 4 feet inwards, parallel to the furnace tubes, and grooved along one side, care being taken to avoid placing the groove so as to allow the feed water to impinge upon the furnace tubes. As the feed water is now usually admitted at a high temperature, the last condition is not so imperative as when cold feed water was the rule. An apparatus is sometimes required for blowing off scum, which forms on some waters. Floating "scummers" are seldom used. With fixed "scummers" a definite unmistakable mark must be made on or near the gauge glass, at which the water surface must stand when scumming, or the operation is useless. Various waters differ exceedingly in their liability to form scum.

One or two gauge glasses must be provided, with cocks in good condition, to be closed every night. If only one gauge glass is used, a set of four plain gauge cocks will be required instead of the second one. A dial pressure-gauge should be placed on the front of the boiler, so as to be constantly in view of the stoker. It may be attached to any part of the steam space, with the intervention of an inverted siphon, to accumulate water and prevent heating of the instrument.

Two safety valves are necessary, one of which is either a dead-weight valve, or a lever valve carefully constructed with knife-edge bearings and a narrow valve bearing, so as to furnish a ready and reliable test for accuracy of the steam-pressure gauge, and to be frequently used for that purpose. The steam-engine indicator is often applied for the same object, and if in good condition it is trustworthy, but on the whole the former test is preferable.

The blow-off valve is usually in the form of a cock with taper

plug. A cast-iron casing is occasionally employed in conjunction with a brass valve-plug, and when the mud is blown off under pressure it is often difficult, or even impossible, to close the valve before the boiler is emptied, owing to the fact that brass expands with heat to a greater degree than iron, and thus the heat from the water passing the cock causes it to become fixed.

Until lately every boiler was provided with a dome, but scarcely any at the present time are so fitted, a few feet of cast-iron piping, grooved lengthways, being equally efficient (if not more so) in collecting dry steam.

Many kinds of tubular boilers have been tried, but, so far, without practical success, owing in a great measure to the impure feed water which is almost universal in the district under consideration. This is more especially the case in towns where (as in Oldham) every firm must provide a cooling pond, or work without condensation. A sewer pipe of 4 inches bore is often regarded as providing a valuable water supply. This class of water is not adapted for tubular boilers, even if the construction and arrangements are otherwise perfect, as the tubes become blocked-up by the impurities. Even the water tubes before mentioned, placed across the furnace tubes and combustion chamber, are often stopped up, unless the manager of the works exercises a strict personal supervision of the interior during cleaning operations.

The feed water is usually heated before admission into the boiler, either by the waste gases from the furnaces or by the exhaust steam. In the former case, the system almost invariably pursued is to provide a series of vertical cast-iron pipes in the flue; these pipes are collected at the top and bottom into nests, and the nests are then connected to one delivery and one supply pipe. The pipes are covered with a layer of soot on the outside, and of scale on the inside; the soot is removed by continuously-reciprocating scrapers, while the latter must be removed by a rude process of boring. The flues are arranged so that the gases may be passed at pleasure through this apparatus, which is instrumental in effecting a marked economy by raising the feed water to boiling point. As steam cannot be raised to an appreciable extent with it, the possible economy is strictly limited, and is usually somewhat less than is supposed. Messrs. Green, of Wakefield, make the best apparatus of the class, and it is applicable to condensing or non-condensing engines.

The exhaust steam is often used as a feed-heating agent in non-condensing engines. In some cases the feed water passes

the boiler feed-pump before entering a worm, placed in an enlarged part of the exhaust pipe; in other cases the exhaust steam and feed water are intimately mixed in entering a vessel somewhat similar to an ordinary injection condenser. In the latter system, much suspended, and some dissolved, impurity is removed from the water by the use of the heater; but, on the other hand, trouble is sometimes caused by the admission of an excessive quantity of tallow into the boiler. The water must then be made to pass the pump after leaving the heater, which causes frequent trouble unless the pump is well designed.

Feed pumps often possess a defect which, annoying in any case, is especially so when they are required to pass hot water. The intermediate space between the suction and discharge valves ought to be at a lower level than the discharge valve, so that all air may tend towards that point, and pass away. Even the small space existing around the ram—where the barrel does not fit the ram to a level below the passage to the delivery valve—is often prejudicial when working at a high pressure, from the expansion and contraction of its contained air with the motion of the ram. On referring to the section of the feed pump in the lower part of Fig. 11, Plate 4, it will be seen that the cover to the suction valve is projected downwards to reduce the intermediate space and to avoid an accumulation at that point.

In many works a small engine combined with a pump, or one of the crankless steam pumps, is substituted for a feed pump connected to the engine. This arrangement at a low speed feeds the boilers, at a moderate speed washes out the boilers after cleaning, and at full speed acts as a steam fire-engine. These combined engines are of various capacities, capable of pumping from 150 to 800 gallons per minute at ordinary speed. Neighbouring works frequently agree to give mutual assistance in case of fire; and when the pipes are well arranged a large quantity of water can be quickly brought to bear on any given point.

Greater care is necessary in these steam fire-engines than in feed pumps to prevent air accumulations, as time is too valuable (when a fire breaks out) to allow for priming before water can be forced out. The steam pumps are usually in, or near, the stoke-hole, so as to be under the easy control of the stoker; but when no room can be spared for such a pump, a Giffard's injector is often employed, either alone, or as an auxiliary to the boiler pump in the engine room. The substitution of an injector for the feed pump admits of the omission of a feed-escape valve, which is otherwise necessary.

Such is a sketch of the boiler and other appliances ordinarily found in the boiler house. In conclusion it may be stated, that the number of boilers used for any given power varies widely according to their age, the pressure, and the condition of the feed water, &c. New boilers work safely at a higher pressure than old ones, and less frequently require to be laid off for repairs. Bad feed water also causes boilers to be more frequently laid off, for cleaning in case of muddy water, or for repairs when water is obtained from mines, or is contaminated by chemical residues.

In ordinary work the Lancashire or Galloway boilers of the present day appear to give the highest evaporation when burning 18 to 20 tons of good coal per week. With interest on outlay and all items of cost added, power appears to be more cheaply supplied when the boilers consume about 24 tons per week of fifty-six hours; the amount of water evaporated, and therefore effective HP., varying with the state of the boiler and other appointments.

In current practice the steam engine is usually of the horizontal class. The power required for any works not already in active operation is not easy to calculate, and is often absolutely impossible, owing to the machinery supplied by different makers for the same purpose differing widely in the amount of power required to propel it. A prevalent pattern is that in which four cylinders are used, one high-pressure cylinder 18 inches in diameter, and one low-pressure cylinder 36 inches in diameter, acting on each crank at the two ends of the crank shaft, the stroke usually being 6 feet; the two cylinders on each side of the centre line forming separate compound engines. The steam ports are ample, 1½ inch by 12 inches being frequently adopted in the high-pressure cylinders, with an ordinary slide valve, 1½ inch lap, 6 inches travel, cutting off at about $\frac{2}{3}$ stroke. The steam passes from this cylinder to one of the larger bore without any intermediate receiver, except that constituted by the intermediate pipe. This cylinder has ports 3 inches by 24 inches, lap 2 inches, travel 10 inches, cutting off at about $\frac{5}{6}$ stroke. Both cylinders are set on one common centre line, and often have one piston rod with the two pistons cottered on; sometimes two piston rods are used, and joined in one piston by means of a cotter through both rods; at other times two rods are used and jointed outside the cylinders; but as the joint cannot enter either cylinder, the total length of the whole engine is thereby much increased. Some of the best engines, of nearly the above dimensions, carry almost the whole boiler pressure of 80 lbs. on the piston, indicating about 600 HP.,

with a consumption of little more than 2 lbs. per HP. per hour, including steam for heating purposes in the works, of which no separate account is kept.

Cut-off motions are often applied to new engines, frequently to be removed after a few years' use. The Corliss valve has not been so largely employed in this country as it deserves, or might have been expected to be. Messrs. Galloway apply a cut-off motion on a similar principle to the Allen engine, and with success. The leading feature is that the eccentric centre is in the same plane through the crank-shaft centre as the crank-pin centre. The clip of this eccentric is held by a link working on a stud at a distance below the centre plane, and is provided with a slot, in which a block is carefully fitted to slide vertically, being actuated by the governor lever. This block carries the stud which fits the end of the link that works the valve spindle. The whole arrangement ensures a variable cut-off and a constant lead or steam admission, one valve only being used for steam supply.

A variable cut-off motion is not of equal value in all classes of work. A cotton or woollen mill usually works up to its maximum capacity, while a saw mill or machine shop is liable to sudden and great variations in the power required. In the former case, there is no necessity for any reserve force; but in the latter the absence of a reserve force would cause the engine to stop. As a waste of power is caused by working on the throttle valve, a good cut-off motion is a necessary part of an economical engine exposed to irregular work. In all cases, however, a simple variable cut-off motion is a valuable addition to an engine; while (where not absolutely necessary) a complicated one may introduce more evils than are compensated by its beneficial properties. Frequently a throttle valve may be found on engines which are supposed to be fitted with an efficient cut-off motion, also worked by the governor.

Recently it was reported that a cylinder 18 inches in diameter had only 3 square inches of steam opening in maximum condition, though the actual opening of the steam port was 11 square inches. This was caused by adding lap to the valve, so as to cut off at one-third to one-fourth of the stroke, with a view to an increased economy. The exhaust opening is, of course, not visible, and the inevitable early release is not noticed. It may easily be seen that this must result in extravagant working; yet this condition of affairs is of frequent occurrence in small works, where usually there is no indicator.

The proportionately great length of the cylinder causes the

adoption of short ports and separate valves at each end of the cylinder. The exhaust steam is thus in contact with the cylinder over an excessive amount of surface; and the amount is often increased by continuing the exhaust passage as a belt to the bottom of the cylinder, so as to place the exhaust and intermediate pipes out of sight in the foundations. This is shown in the exhaust-passage arrangement of a low-pressure cylinder, Plate 4, Fig. 13. The valve spindle is generally carried through the valve, a tube for that purpose being cast in each valve. The engagement may be either by locked nuts, collars (both of which are shown in Fig. 15), or by a tube fitting the valve-spindle, and bearing against the inner surface of the nuts, preventing them approaching sufficiently near together to hold the valve. In all these arrangements the valve must freely lift to a slight extent to let the water from the cylinder escape. Yokes are now seldom used for the valves of engines of this class. The laps of valves are often cut off obliquely, or to a V shape, to allow of the more gradual admission of steam.

The usual valve motion is produced by eccentrics on the crank shaft, separate eccentrics being used for each cylinder, so as to give greater range of adjustment. The eccentric sheaves are split and held together by turned bolts, and the clips are of cast iron (Fig. 15a) often (though unnecessarily) bushed with brass. When the crank pedestals are of sufficient length, it usually occurs that the eccentric rod is farther from the centre line of the engine than the valve spindle; some method is then necessary for the connection of the two. The best connection is by means of a short, stout, cast-iron lever, carried by a rocking shaft, and with a stud through the top boss, one end of this stud engaging the eccentric rod, and the other end the link which is attached to the valve spindle. A more usual and elegant method is to provide two separate wrought-iron levers keyed on one shaft; but in this case the torsion of the shaft and the deflection of the levers cause the motion to be unsteady. Where the eccentric rod is of great length, it must be provided with a joint near the centre of the length, and a supporting lever. A good joint for valve spindles and eccentric rods is shown in Plate 3, Figs. 8, 9, and 10, care being taken in employing ample proportions. The valve spindle is usually supported by a bracket outside the stuffing-box, a good packing space being left. A solid cast bracket, bored to fit a bush of cast iron, which fits the valve spindle (and is easily renewed when worn), is a very successful form of valve-spindle guide.

It may here be noticed that in some cases (as in Figs. 11 to 14) the larger or low-pressure cylinder is nearer to the crank shaft

than the smaller or high-pressure cylinder, while in others the reverse order is observed. The valve gear is more compact in the latter case, as the eccentric nearest to the engine centre works the valve spindle; while in the former the reverse order obtains, two levers on one vibrating shaft being sometimes quite necessary. The valve gear of the rear cylinder ought always to be arranged to allow the rear cover of the fore cylinder to be removed for inspection and cleaning, without interfering with the valve gear in any way, and without demanding an excessive intermediate space between the two cylinders. It is obvious that this condition can be much more easily fulfilled when the larger cylinder is in the rear position, because, first, the cover which requires to be left free is then the smaller one; and secondly, the valve gear is farther from the centre of the engine, and therefore not so obstructive.

Slide valves are seldom balanced to relieve the pressure on their faces, and consequently require powerful gear to drive them quite steadily. Many gears transmit an unsteady motion to the valves.

The system of framing, in which the working strains are directly opposed, has not yet met with extensive adoption in the district. The leading idea is to provide a bed plate of sufficient weight and strength in the estimation of the builder and the owner. This bed plate has an approximately flat upper surface, prepared to receive the loose crank-pedestals, the slide bars or parallel motion preparation, and the two cylinders, the common centre line of which is kept as low as possible in order to reduce the bending action. Though not strictly correct in principle, this class of bed plate is successful in practice, and has several good features. Two different arrangements of the end carrying the crank shaft are extensively adopted, both of which are shown in Fig. 12, one in full lines, and the other in dotted lines. When the part directly beneath the connecting rod is carried far towards the crank shaft, a recess becomes necessary, in which the connecting rod is to work; and this is essentially necessary when the centre of the cylinders approaches the top of the bed plate. This recess is frequently condemned as an unworkmanlike proceeding, but its use is often compulsory. When the bed plate exceeds 30 feet in length, it is more convenient, for casting and transport, to cast it in two or more lengths, which are then connected by dowelling. The bed plate must be held to the foundation by a sufficient number of holding-down bolts; where practicable these should be arranged at intervals not greater than 6 feet apart; but this

is only imperative near the crank shaft, where, however, there is seldom any obstruction. Where the bolts cannot be placed at intervals of about 6 feet, the builder must use his discretion as to the proper arrangement to be adopted. Lewis bolts are sometimes used, but long bolts, reaching to the bottom of the stone foundations, are to be preferred, and are almost universally used; a hand hole is provided which allows access to the lower end of the bolt, and is occasionally convenient in permitting the bolt to drop a short distance. The preparations for all attachments are planed in good work.

The air pump is generally worked by a bell-crank lever, by means of a pair of short links connecting the top end of the lever to the crosshead; therefore, the air-pump centre is nearly under the centre of the crosshead. The bell-crank lever shaft is carried by a pair of pedestals, which are either secured in or to the stone foundation, or to a pair of cast-iron frames, fastened to the lower side of the bed plate. This arrangement is only adopted in engines possessing slide bars. The pump rod requires guides, either in the form of slide bars or a trunk; if slide bars are employed, they must be sufficiently far apart to permit the free withdrawal of the air pump, cover, and bucket. The feed pump is most advantageously worked by a lever on the end of the air-pump rock shaft, as shown by its situation in Fig. 11. When this shaft is abolished, as when horizontal air pumps are employed, the feed pump may be worked from the crosshead; but this proceeding never fails to cause the crosshead to follow a crooked course, unless special means be taken to prevent it.

If a horizontal engine be provided with a parallel motion, the air pump is often placed below the engine-room floor, to the rear of the cylinders. There it is actuated by a bell-crank lever, but the top of the lever is worked by a connecting rod from the centre bar of the parallel motion. The connecting rod passes beneath the cylinder or cylinders, and the whole arrangement is directly derived from that of the beam engine, with the addition of the bell-crank lever to change the direction from horizontal to vertical motion. This is more usually adopted where only one cylinder is placed on one frame, otherwise the connecting rod becomes excessively long.

Vertical air pumps are firmly attached to the stone foundation beneath the engine-room floor, and are provided with brass foot valves, indiarubber bucket valves, and indiarubber delivery valves, either whole or in the form of a number of smaller circular valves, attached to a cover plate provided with a stuffing box,

through which the pump rod slides. The acting surfaces of guards for indiarubber valves are often curved in vertical section to a radius equal to their diameters, in which case very little lift is allowed at the centre of the valve. Many owners prefer flat guards, in which the lift is equal throughout the valve, and the friction on the stud greater; therefore the wear in the eye of the valve is greater, but the tendency of the valve towards breaking across is reduced. The preference is often ruled by the action of water on the rubber. The outer surface of the bucket is sometimes solid; or it is packed with wood, of which alder is the best; more frequently it is provided with metallic packing. The part of packing which comes into contact with the bore of the pump barrel must be of brass, which, though actually wearing faster than iron, is not damaged by corrosion, and does not damage the bore of the barrel to the same extent.

Horizontal air pumps have recently been applied to a large number of horizontal engines. Some are double acting, and others single acting, very similar to that adopted in the Allen engine. Unless great attention is paid to the piston in double-acting air pumps, the leakage may become serious; and the same may also be said of the pistons in steam cylinders. The single-acting air pump has a ram or plunger working through a stuffing box into the pump and into the atmosphere. The box should be packed by first placing in it a little flax or hemp, then a metal ring of ⊢ section, and afterwards more flax or hemp to fill the box. The ring must have one plane face against the lower and one against the upper fibrous packing, and also a few holes bored through the distance piece, or what may be called the web. A pipe of $\frac{1}{4}$-inch or $\frac{3}{8}$-inch bore enters the stuffing box opposite this ring, and conveys water into it from the hot well. The pump is thus found to make and maintain its vacuum better than without it, and the gland may be slacker in the stuffing box, thus diminishing the friction. Horizontal air pumps are chiefly employed where some obstacle prevents the use of a vertical air pump below the floor; they might be more frequently adopted with advantage. From their usual position behind the cylinders, and on the same bed plate, they possess one objection, that when a short stop is made during ordinary working hours the injection water ought to be stopped. This, however, is often omitted during the confusion attendant on such stoppages, when, first, the air pump cavities are more or less filled, and then the water overflows into the cylinder, ready to cause mischief if the start is suddenly made. This may, of course, be obviated by raising the exhaust pipe, and

by opening the water-escape valves on the cylinder, so as to destroy the vacuum by the admission of air. The injection valve need not then be touched (unless the water is delivered under pressure), which is an advantage if the valve is closely adjusted to give proper opening.

In some cases, two cylinders only are employed, whose equivalent diameters are 25-inch and 48-inch, or 50-inch, with a stroke of 6 feet as before. Each piston propels a separate crank on the opposite ends of a crank shaft; the crank, which is driven by the high-pressure piston, being set 135° in advance of that driven by the piston of the low-pressure cylinder. This arrangement is somewhat cheaper in first cost and maintenance, while it is little, if at all, inferior in producing an equable motion. When the cranks approach positions directly opposite to each other, there is a small saving in coal, at the sacrifice of some degree of equable motion.

Steam cylinders are usually moulded in loam, the inside being formed by a separate core; both mould and core must be thoroughly dried, either in a stove or by a special fire built underneath. The cylinders are moulded and cast in a vertical position, whatever position they may be intended to assume when complete; the upper end in casting is left longer, forming a head, which is cut away when the casting is bored, and leaves the effective casting more dense in texture. The ports are made as direct as possible, to reduce the clearance (Fig. 15); the slide valve is then divided into two; also two separate exhaust ports are required. As before mentioned, this causes the exhaust passages to have a large area of surface in contact with the cylinder body, and leads to a larger area of valve and increased friction, unless (as is seldom the case) the valves are balanced. It may be noticed that a cylinder, 18 inches in diameter by 6 feet stroke, is a somewhat awkward casting; and the ports, if a single valve was employed, would require more delicate treatment than moulders usually bestow upon any work, so that practically the short ports are most successful. The covers project 2 to 3 inches into the cylinder, because the port must reach to the cover, and there must be sufficient material outside the port to hold the studs of the cover. The studs ought to avoid the horizontal and vertical planes through the centre of the cylinders; this may also be advantageously extended to the covers of the valve chests. The covers must be provided with ample stuffing-boxes, so as to avoid frequent replenishing, and also the friction consequent on screwing down the gland excessively, which is necessary to hold the steam if the boxes are shallow. The cylinders must be carefully bored in the

first instance, and the bore tested throughout; they also require re-boring from time to time, and as the covers must still fit the bore, the cylinder is counterbored in the first instance, $\frac{3}{4}$ inch to 1 inch larger in diameter at each end than the working bore of the cylinder; this counterbore is not afterwards touched. The parallel working bore of the cylinder is of a length equal to the stroke + the width of one piston-casing ring, where two casing rings are employed without an intermediate flange. By this means each casing ring works beyond the parallel bore of the cylinder at each end of the stroke to the extent of half its width, thus preventing the formation of shoulders in the bore of the cylinder.

An efficient elastic piston of the spiral class is made by many makers, and is well received by owners. The steam piston is shown in section in Fig. 15; it is provided with a loose junk ring, to allow access to the packing. The junk ring is secured by set screws, with brass nuts and brass washers; there are two or three set screws, which may be removed, and the holes may receive forcing screws for easing off the junk ring. Beneath this junk ring a circumferential groove is turned to receive the packing. The packing consists of two parts: an inner spiral spring and an outer pair of casings. The ⌊-shaped casings only are shown; they are turned of a diameter somewhat larger than the bore of the cylinder, and are cut obliquely across, one part to the right hand, and the other to the left hand; they are then forced apart, and also radially from the centre, by the inner spiral spring. Some makers employ a special kind of cast iron in the construction of these spiral springs, while others employ steel. The casings are made from good free cast iron when for steam cylinders, and from brass when for air-pump buckets. The casings and spiral spring are obstinate in "putting up," but after a little practice this is overcome, steel being the more refractory in this respect. When well made, and the bore of cylinder in fair condition, these pistons and buckets are invariably successful.

Each cylinder is secured against longitudinal movement at one end only; this is to allow the expansion and contraction caused by variation in temperature to take place freely, as the other end is only bolted down, and the bolt holes are larger than the bolts. Formerly, the practice was prevalent to hold the cylinder by separate feet at each end; but latterly, the foot is continuous throughout the length, or is placed in the centre and made of ample length. Longitudinal movement is prevented by a key, sunk one-half into the bed plate and the other half into the cylinder foot, either at the centre of the length or near the end

towards the crank shaft, so that the cylinder and the piston rod expand simultaneously when heated. Should the arrangement or dimensions of the valve chest preclude the existence of a foot in the ordinary manner below the valve chest, the bolts holding the cylinder to the bed plate are sometimes passed through the valve chest, in which case great care must be exercised to avoid contracting the steam or exhaust passages. It is occasionally convenient to continue a bed plate holding-bolt through the foot of the cylinder, and thereby save one bolt, introducing a bed plate holding-bolt where it would be otherwise impossible to do so.

Each cylinder should be provided at both ends with a valve, opening outwards, and of area sufficient to allow the escape of any condensed water which may exist in the cylinder. These valves are often closed by weights and levers, but the inertia of the weights frequently prevents the prompt release of the water before the cylinder is cracked. Spring valves are much more prompt in action, though not so easy of adjustment. Probably the best arrangement would be a combination of the two, by inserting a spring between the lever and the weight.

The best piston rods are of steel, which is stronger than iron, and not liable to flute. They are usually fixed in the piston, as shown in Fig. 15, by a split cotter, the piston rod being bossed to a larger diameter at that point, and turned taper. The piston rod is turned taper to fit the bore of the crosshead without increase of diameter, which would necessitate the splitting of the gland (or its brass bush) to pass over the end of the piston rod. The crosshead cotter may be inserted horizontally or vertically as may be most accessible for insertion and removal.

The crosshead is usually of wrought iron, but cast iron may often be advantageously employed, allowing somewhat larger dimensions; the patterns vary very much.

Connecting rods are commonly arranged with the distance of the centres equal to the length of stroke multiplied by 3; sometimes both ends are single, but more frequently the crosshead end is forked. The forking of the connecting-rod end is, however, not so desirable as forking the solid crosshead where possible. By forking the connecting rod the forging is more elaborate, the brasses, strap, gibs, cotter, &c., are all duplicated, and a great risk of occasional side strains (caused by careless cottering) is introduced. The latter contingency prevents the adoption of the same refinement of proportion that could otherwise be attained, because each side must be strong enough to withstand the whole strain in itself; the possible existence of this side strain also

demands a more secure arrangement of slide bars or parallel motion. If the crosshead is forked instead of the connecting rod, the number of parts is reduced to a minimum, and the greater complexity of the crosshead, whether of cast or of wrought iron, is little more than equivalent to that of the forging only of a forked connecting rod. In the case of a forked connecting rod, whether the crosshead end is single or double, it is almost invariably provided with brasses, straps, gibs, and cotters, as shown in Figs 17 to 19 (Plate 3), of various proportions suitable for either connecting rods, pump rods, or valve gear; the gib nearest to the end of the rod is usually omitted in light work. In Figs. 20 to 22 a class of rod end is shown which is equally suitable for either end of the connecting rod, and is occasionally employed in other situations. The end of the rod is first forged solid, and a rectangular eye is cut through it; a pair of brasses and a wrought-iron wedge of the form shown are then fitted, and the wedge is provided with an adjusting screw, which is fixed either by a pinching screw, or by manipulating the lock nuts.

The marine pattern of crank pin and connecting rod, Figs. 23 to 25, is now coming into extensive use; here the tension is borne by two stout bolts, and the brasses are more bulky than appears at first sight to be necessary. They give much less trouble by heating than any others; this is probably due to their bulky character, which, when assisted by the bolts, tends to prevent the distortion caused by heat. Whatever the arrangements of connecting-rod ends, the adjustment for wear at both ends ought to be towards the same cardinal point, with a view to preserving a constant distance of the centres. This is, however, not absolute, as the crank-pin brasses usually wear more quickly than those at the crosshead end.

Bearings of wrought iron working on gun metal ought not to sustain a greater pressure perpendicularly to the axis of the shaft than—the diameter in inches × the length in inches × 400 lbs.,—otherwise the risk of overheating becomes serious. In other words, the load may not exceed 400 lbs. per square inch in the longitudinal plane section of the bearing.

Phosphor bronze now enters largely into the construction of important bearings, allowing a greater pressure to be placed on it than the above. But nevertheless it is advisable to work as near the above figure as possible, to maintain the bearing surfaces in first-class condition. Crosshead and other slowly-moving oscillating bearings may be (and usually are) loaded to a much higher degree than would be possible under other circumstances.

The most common form of crank is that shown in Figs. 11 and 12 (Plate 4), being the old pattern wrought-iron one, fixed upon the shaft and the crank pin when hot. A key is driven between the crank and shaft, to prevent rotation on the shaft. The crank pin is fixed, either in a way exactly similar to the shaft (in which case the hole is bored parallel), or the hole is bored taper, and a cotter driven through the boss of the crank and pin, to prevent it from working out. Cast-iron disc cranks are occasionally employed, but are liable to split across in fixing upon the shaft. This is more frequently the case when the crank is arranged to balance the connecting rod, and the work is not skilfully performed.

The crank is the only admissible situation for a weight to balance the half connecting rod. In single-crank engines, however, the fly wheel is often weighted with that object in view, though situated several feet from the crank. This balance allows the engine to be more easily moved by hand, with the assistance of a bar; but when the engine is steaming, its action is decidedly prejudicial. The subject of balancing shafting is subsequently referred to.

The crank shaft of an engine of the class in question is 11 to 12½ inches in diameter in the journals; these dimensions being sufficient to cause the pressure per square inch not to exceed the figure (400 lbs.) before mentioned. In many cases, however, less than half that pressure is really applied, such proportions being justified by the results. The majority of crank shafts are made from wrought-iron forgings, but mild steel is frequently and successfully employed at the present time. Sir Joseph Whitworth's fluid-pressed steel makes the best shafts in the market, but comparatively few owners care to meet the cost of this material.

The crank shafts of horizontal engines are usually carried in angular pedestals with top and bottom brasses, the joint being inclined at an angle of 40° to 50° with the horizontal plane. Fig. 16 is an elevation of such a pedestal. Several of the old engines with flat pedestals are more reliable as to freedom from heating in the crank bearings. The fact that some makers turn the cap towards the cylinders, while the majority take an opposite course under similar conditions, tends to show that the flat, or level-jointed pedestal, would do as well as the angular form. The angular pedestals are often arranged so that the oil is scraped off the journal, at the lower side of the joint, before it reaches the point of greatest effect at the bottom of the bearing. In the class of engines in question, one-half of the weight of

the fly wheel, crank shaft, &c., which rests on each bearing, is quite competent to prevent the shaft from climbing out of its proper position in the bottom brass. This view is confirmed by the fact, that brasses which are worn sufficiently to require renewal have suffered most in the part directly under the centre of the shaft; any deviation that occurs is towards the lower side of the joint of the brasses. In high speed single-crank engines, with a light fly wheel, or with a fly wheel placed much farther from the crank pedestal than from the other pedestal, the fly wheel is incompetent to perform the same office satisfactorily, and some other arrangement becomes necessary, whereby the thrust of the connecting rod may be efficiently and directly resisted. This is not so in the case under consideration. From an engineer's point of view the fly wheel appears unnecessarily heavy, but the owners find that their interests are best served by the employment of such wheels; when this is the case their effect upon the bearings ought to be carefully studied.

The pedestal is bored out, and the exterior of the brasses is turned to fit the bore of the pedestal. Snugs are provided on brasses to prevent their rotation, and consequently the finishing of the brasses outside, over a strip of surface equal to the width of the snugs, cannot be accomplished; this strip is cast to stand below the turned surface, and is therefore unsupported. The best holding snugs are situated close to the joint of the brasses, and only on the effective side of the bottom brass, so that when the weight of the shaft is relieved, the brass may be easily slipped around to the upper side of the shaft, and removed. These snugs are generally cast on both sides for use in turning and boring the brasses, and afterwards one snug is cut away. A hole in the end of each pedestal, drilled and tapped to receive a set screw of sufficient strength to lift the shaft, wheel, &c., is convenient for adjustment, inspection, and repairs.

The fly wheel is often made with one hundred and fifty-two teeth, 5 inches pitch by 15 inches wide, if eight arms are employed; or one hundred and fifty similar teeth, with ten arms: in both cases the diameter is nearly 20 feet, and the weight 25 to 35 tons. The arms of the wheel are driven into sockets, which are cast, and afterwards bored out in a central boss; the boss is secured to the shaft by four keys, which fit flats on the shaft and keyways in the boss; the boss is not bored, but has the eye cast of a diameter larger than that of the shaft. Two keys have heads and two have points towards each side. This allows some adjustment of the wheel, which would be impossible if the boss was bored; but its

chief value lies in the fact that the facility of handling both the wheel and the shaft, either during erection or subsequently, is thereby increased. Each arm is secured in the boss by cotters, and is prepared at its outer end (by a flange or plate) for the reception of the adjacent ends of two fly segments, whose office is to give sufficient weight to the wheel, and which are bolted to arm ends. The fly segments may be furnished with snugs, to admit the use of keys or floats against the ends of the arms, and thereby increase the stability of the wheel. Two arms are shown (Fig. 11) prepared for keys, and two without such preparation. When snugs for keys are adopted they prevent the possibility of turning at the inside of segments to receive the ends of the arms, unless the snug is only carried part of the way across the segment, and the bedding performed on the remaining part. In such cases the end of the arm is often surfaced in the lathe with the same centres as are employed in the turning of the spigot to fit the boss; this surface is then plane and perpendicular to the centre of the arm, while the surfaces (chipped strips) of segments, which fit to the ends of the arms, must be finished by hand. The outer surfaces of the fly segments are prepared for the reception of an equal number of tooth segments, the joints of which are arranged midway between those of the fly segments. These tooth segments are cast with the utmost regard to the attainment of a suitable section, with a view to prevent sacrifice of strength in any part, which may be caused by the presence of large or unequal masses of metal. Formerly the custom was to arrange one set of segments only to serve both purposes, though sometimes cast with recesses, which were afterwards filled with a bulky casting in each; these constantly gave trouble from the teeth breaking close to the rim, and the system is now abandoned in this district. Figs. 11 and 12 show a good ordinary wheel of the class described.

The pendulum governor is the one most largely used, being the Watt governor with a slide on the spindle, at about the same height as the centre of the balls, instead of the parallelogram at the top of the spindle. The controlling motion is taken off, either by a hollow spindle containing a rod passing upwards, or by a groove in the bottom slide which contains a collar (or its equivalent) with a pair of opposite studs working a forked lever, if the motion is required downwards. The arms are usually suspended at points on each side of the spindle, about 2 inches from the centre of the spindle, or 4 inches from each other. The more correct plan, of fixing the point of suspension on the centre of the

spindle, is seldom employed. The diameter of the balls is 10 to 11 inches, and the length of the arm is such as to give about the same working number of revolutions (thirty-three to thirty-six) to the governor spindle as to the crank shaft. Neglecting the influence of the arms and links, the number of revolutions per minute $= \frac{187 \cdot 5}{\sqrt{h}}$, where h = height in inches of the intersection of the centre of the arms with the spindle centre, above the straight line joining the centres of the two balls. In ordinary cases the number of revolutions, obtained from the above well-known rule, may be increased by the addition of three to the required number of revolutions, to compensate for the influence of the arms, links, and parts sliding on the spindle, thereby dispensing with complicated formulæ and calculations, while still arriving at a good practical result. If the arms, links, and sliding parts are of extra weight, a greater number must be added.

Governors have been successfully employed with the point of suspension of each arm, and the weight attached to each arm, on opposite sides of the spindle; therefore, the actual arms (instead of the arms produced) cross in the centre. In many cases governors on the high speed principle, with light balls driven at a great speed, and a heavy balance weight sliding on the spindle, to counteract the centrifugal force at a certain speed, have been employed; many forms have been adopted, of which Porter's and Galloway's may be taken as types. The two latter systems of governor are more sensitive than the first or ordinary one (in fact, Porter's is sometimes too sensitive), but they have not met with the extensive adoption which they deserve. As the necessity for equable motion in most of the works of this district is of the highest importance, this is surprising.

As before mentioned, the usual means for regulating the supply of steam is by a throttle valve worked by the governor. The old disc valve swivelling across the steam-supply pipe is fast disappearing in favour of the equilibrium valve, having an upper and lower seating, each with corresponding conical valve, the steam being admitted either between the two or outside. The two discs are sometimes absolutely of equal diameters, in which case no ready means of taking the apparatus apart exist; more frequently the lower valve is made of a smaller diameter, and with specially narrow bearing, so as to have the difference as small as possible; the valve may then be thoroughly taken apart in the minimum time. No difference in working effect can be observed until the valve is practically closed, and then it is very small.

Two classes of stop valves are shown in Figs. 26 and 27; one is usually called a stop valve, and the other a junction valve, but at some shops the names are reversed. In Fig. 26 the entry is at the bottom, and the exit at the side. The valve shown in Fig. 27 is merely inserted in a straight, continuous pipe. The valve disc itself in Fig. 26 is winged; in Fig. 27 it is a spindle or mushroom valve. In Fig. 26 the spindle is provided with a nut below the bonnet; in Fig. 27 the nut is above the bonnet; either kind of bonnet, nut, valve, and seating may be employed in either kind of casing. The casing shown in Fig. 27 provides a fluid way throughout equal to the clear area of the bore of the pipe; the valves mostly employed, however, fall far below fulfilling this necessary condition. The dotted lines in Fig. 27 represent a more common form of casing, and it is not rare to find the area reduced to less than one-half that of the bore of the pipe. The flanges ought to be well secured to the body of the casing by ribs or brackets, but these are often omitted because they interfere with the bolts.

The steam-supply, intermediate, exhaust, and water-injection pipes, are usually all below the floor of the engine room. The steam-supply pipe is provided with a stop valve. When two high-pressure cylinders are employed, a main stop-valve is inserted in the steam pipe before branching, and a smaller auxiliary valve in the branch leading to each cylinder. Ordinarily, the smaller valves are kept wide open, and only the main valve is worked, except when one cylinder is stopped. A similar but smaller valve is also employed to communicate between the steam and intermediate pipes, for convenience of warming by the admission of steam before starting. These valves are sometimes replaced or supplemented by brass by-pass cocks, which communicate between the steam chest and the steam port (independently of the position of the slide valve), and which, besides convenience in warming, are of great assistance in starting the engine from a fixed position; or, by introducing a retarding steam pressure, they assist in stopping it in a required position. The valve which regulates the supply of injection water is usually a sluice valve worked by a screw; some firms employ cocks for this purpose. The water reservoir is seldom above the injection inlet, owing to the fact that the water is to be repeatedly used, and if the reservoir was elevated, the back water would require pumping accordingly. When the injection water is not delivered under pressure, and the work is regular, the valve may be untouched for weeks together. All the valves, when beneath the engine-room floor, are worked by continuations

of their spindles to a distance of about 2 feet 6 inches above the engine room floor, and supported by pillars. In Fig. 11 the intermediate pipe is shown to take an overhead course, because more direct, and avoiding the awkward joint necessary on the high-pressure cylinder beneath the valve chest; but usually this inconvenience is disregarded for the sake of appearance. It will be noticed that the joint of the exhaust pipe with the low-pressure cylinder is inaccessible; it is made before lowering the cylinder to the bed plate. The exhaust pipe is not well arranged in Fig. 11 to expand and contract freely; but as the range of temperature is small, there is no trouble on that account. Very few expansion joints are now fitted in steam pipes, as an elbow with the two arms at right angles, and of considerable length, is found to act satisfactorily. In the class of engine under description, the diameter of the steam pipe is equal to about one-third that of the high-pressure cylinder, the intermediate pipe being equal to one-half that, or one-quarter of the low-pressure cylinder, and of equal diameter throughout its length. The diameter of the final exhaust pipe is equal to that of the low-pressure cylinder multiplied by 0·32 to 0·35 at its upper end, being usually somewhat larger at its lower end or junction with the condenser. The description just given applies with little modification to a large portion of the engines now being erected, or recently set to work, in the district.

Twenty years ago the beam engine was largely adopted, and many examples are now at work yielding creditable results. The strains to be resisted in such engines act at many points, in a great measure independently of each other, which causes total cost of the engines and of the foundations to be heavy. The beam is frequently a weak point, giving much trouble and expense by breaking, and causing the fracture of other details. On the whole, therefore, the beam engine is an expensive form of steam machinery. On the other hand, when the details are all well proportioned as regards strength, the system gives a uniform motion, offering great facility for working the pumps, and comparing favourably for general accessibility with many others.

Beam engines are occasionally applied at the present day, but their use is limited, and is decreasing. The great majority of beam engines now working, whether new or old, are compounded on McNaught's system; the cylinder, which in the original form was used alone (engaging the end of beam), being employed as the low-pressure cylinder, while a high-pressure cylinder is

erected below a point in the beam about half-way between the main centre and the connecting-rod stud. The capacity of this high-pressure cylinder is from one-third to one-fourth of that of the original, or low-pressure cylinder. When well-proportioned to the required work and to the boiler pressure, the addition of such a high-pressure cylinder to an existing beam engine conduces to economical working. At the same time another important advantage is obtained, and this is often the primary reason for such alteration, viz., the two cylinders being on opposite sides of the main centre of the beam, assuming the work performed in the two separate cylinders to be equal in amount, there is no more pressure on the beam centres when the engine is working than when it is standing. The degree of closeness with which the above assumption agrees with the facts rules the action on the beam centres; but in every case the tendency is towards the same result, viz., to relieve the beam.

In Woolf's system of compounding, the two cylinders are arranged beneath the same end of the beam, and the connecting rod is applied to the other end; this is with a view to reduce the cubical capacity of the passages, and to promote economy. Obviously this system does not relieve the beam, and is only to be attempted when the appointments are good.

Another principle (which in approximate chronological order may be placed between the beam engine and the horizontal form) is that of the vertical engine, with the cylinder on the foundation and the crank shaft overhead. In this case the air pump is below the level of the cylinder, is worked by means of a lever from the crosshead, and is often only accessible with difficulty. The cost of foundations for this type of engine may be small (as also the total cost) by judicious arrangement, but this is never a conveniently-worked engine, and is now seldom employed in new work. As in all engines, the crank shaft is the part most difficult to control; here it is situated very inconveniently for being well secured.

Several firms are erecting vertical engines with overhead cylinders with fair success, as might be expected from the results of their use as marine engines. They occupy less floor space than others, except the last described. The motion is at least as steady as that produced by any other reciprocating engine. The question of the side adjustment of the crank-shaft brasses is solved in a decided manner, unless materially influenced by the direction in which the work is taken off, and even then an advantage over the horizontal engine still remains. The whole weight of the engine rests on the foundation plate near the crank, and where most

desirable for steadiness. No side stays are required, as all motion above the crosshead takes place in an absolutely vertical direction. The air pump may be worked by a lever from the crosshead, and placed on the engine-room floor, allowing free access to all its parts. The piston is also readily accessible, as the cylinder cover may be removed. The wear of the piston and bore of the cylinder are equal throughout the circumference; while assurances are freely offered to the effect that the wear on the lower side of pistons and cylinders is very small, or even absent, yet the contrary is constantly shown to be the case, many pistons being in a wretched state from this cause. Some engines of this class scatter the drip from the piston rods and valve spindles, causing a slovenly appearance; but this is not an insurmountable obstacle, and even if it were so, it would not prove a serious objection.

A most important point to be regarded in the design of this type of engine is, that the frame must be scrupulously symmetrical with respect to the vertical plane traversing the axis of the crank shaft, and also with respect to the vertical plane which is perpendicular to this one, and traversing the axis of cylinder. If any departures be necessary for the attachment of the valve or pump gear, they must be reduced to the lowest limits. If the crank bearing be firmly supported (or, better still, be duplicated and well supported on the opposite side of the above second plane), the whole engine may be confidently expected to perform its work well and without vibration.

Steam jackets have been repeatedly adopted and discarded, chiefly because attention was not paid to the conditions necessary to their economical working. The steam should be supplied to the jacket independent of the supply to the cylinder, or at least should be taken away from that pipe before passing the stop valve, with a view to obtaining as nearly as possible the full boiler pressure (and therefore the full boiler temperature) in the steam jacket. The drainage also requires careful attention, and must be arranged so that every drop of water is removed at once on its formation. If the cylinder is sufficiently elevated above the level of the boiler, the drainage pipe may be connected to the water space of the boiler, but such connection is not to be recommended. Another reason why less benefit is derived from the use of jackets is, that the measure of expansion obtaining in the high-pressure cylinder is not great, therefore the range of temperature, with or without jacket, is not so great as when the whole expansion occurs in one cylinder. The steam jacket ought to be applied to both cylinders, but this is seldom the case in compound engines.

Chiefly for these reasons steam jackets have failed to give appreciably beneficial results where they have been adopted. As a small failure goes a long way against any principle, it may be expected that steam jackets will form no exception, and that they will not be largely adopted for a long time to come.

The usual rate of piston speed is about 400 feet per minute; some firms adopt a rate of 500 feet, and others 600 feet or more, with success, but they are exceptions. Occasionally an engine is driven at a higher speed, to relieve it a little when overloaded. If these alterations are made without judicious corresponding ones in the valve gear, the coal consumption rises; more especially when a cumbrous engine constitutes a considerable part of the load. From repeated observations the conclusion is arrived at that high speed in itself necessitates a greater coal consumption. A high piston speed, when judiciously adopted in connection with an efficient expansion arrangement, forms a valuable feature in economical working arrangements, but otherwise it is a snare. In many cases the driving wheels have been removed in favour of a pair of different ratio, allowing the engine to run at a higher speed, without any alteration having been made in the valves and gear to provide for greater expansion; the only possible logical result being arrived at, that the coal consumption is much greater; more especially when the exhaust ports and passages are restricted in area.

The design of steam engines tends to become plainer with each change. Moulds, fluted pillars, carved bases, and other distortions, are replaced by simple curves, either single or double, in which approximate ellipses and parabolas predominate. This is caused partly by the exigencies of prime cost, but also largely by the tardy recognition of the fact that a style, which is beautiful when skilfully wrought in marble, and seen in the open air of a sunny climate, appears under adverse circumstances in the confined space of an engine room, when reproduced in cast iron, with the defects of moulding added. The current practice is to avoid scooping out a space for a nut and washer, or a bolt-head, when these occur obliquely on a surface. A boss is added, instead of removing material, in the large majority of cases; in fact, the principle is often pursued to excess, as, for instance, where an internal angle is carefully filleted, and then the hollow is practically obliterated by the addition of a bolt-hole boss, or facing. This occurs when the length of the internal angle is only a little greater than the width of the boss or facing.

The practice of providing, during the manufacture and erection

of all engines, for the quick and easy removal, for inspection, cleaning, and repairs, is extending. This is chiefly effected by liberally drilling and tapping holes for the insertion of forcing screws, obviating by this means the unmechanical forcing apart of details by chisels, &c. Holes are also drilled and tapped, to receive eye bolts (which also make good forcing screws), to which the lifting tackle is readily applied. The cost of these small provisions is amply covered by their convenience during the erection of the engine.

Another practice, recently adopted, is to build up the walls of the engine room at once, before erecting the foundation. At a suitable height, provision is made, either by a cornice or corbels, for the reception of a range of rolled joists along each of the longer sides of the engine room, usually leaving about 3 feet above the top of the rolled joists to the ceiling of the room. Rails are then placed on the rolled joists, and the rails carry a travelling crane, movable in two directions. The crane is arranged to work from below by endless ropes or chains. The hoisting winch consists of a chain barrel, worm wheel, and worm, mounted on two or more pieces of the frame by two shafts. The use of the worm and wheel gives the simplest motion, being reliable, and dispensing with the use of a brake or ratchet wheel, with its attendant cord. The crane used in erecting the foundation and engine afterwards remains as a permanent appointment in the engine room. The success of this practice is modified by the fact that, for the attainment of an economical result, the stonemason requires that his hoisting be performed at a greater speed than the engine builder can admit, therefore the same arrangement is not suitable for both parties. To some extent this objection may be surmounted by changing the worm and worm wheel; the chain barrel, or the whole winch, still retaining the longitudinal and transverse joints.

A few years ago the practice in building engine foundations was to commence by laying a sheeting course, 4 to 6 inches thick, over the whole area, projecting a few inches on each side. The centres of the holding bolts in horizontal projections were next marked on the sheeting course, and a course of brickwork built up about 12 inches high, leaving $7\frac{1}{2}$ inches on each side of each bolt centre, forming an open hand hole for access to the lower end of the bolt. On the top of this the solid stonework was carried up to the required height, in courses of 12 inches to 18 inches, leaving the holes for the holding bolts during building, except the length through the top course, which was marked from the bed plate and drilled afterwards. Recently, however,

owing to the increased cost of stone, the intermediate courses have been dispensed with, only the base course (next above the brick hand hole course) and the top course being retained; while brickwork is substituted for all the intermediate courses. Rough wood boxes are built in the brickwork at each bolt hole, to preserve the vertical opening. The brickwork is set in cement, and appears fully as substantial as stonework. Sometimes also the course of stone next over the hand hole course is omitted, cast plates being laid in its place, and over these the brickwork. Occasionally the sheeting course is stepped out to different levels, as there is no necessity for the whole area to be carried as low as the part below the air pump, if a solid bed is reached at a higher level.

Before leaving the steam engine, it may be mentioned that there are two methods in use for heating the works. In the older system, cast-iron pipes, about 4 inches in diameter, were employed as radiators, the steam being supplied by wrought-iron pipes of smaller diameter, and the condensed water conducted from the cast-iron pipes by traps to wrought-iron pipes. The traps for allowing the escape of the condensed water are of various patterns, the older ones working chiefly on the principle of the ball-tap and cistern, more or less modified.

The more recent forms of traps depend upon the expansion and contraction caused by changes of temperature for their action. One arrangement is similar to the ordinary screw-down stop valve, the valve disc of which is connected to an iron pipe, while the seat is connected to an inner copper pipe. In a decreasing temperature the upper pipe contracts more, opening the passage for the exit of the contents; the reverse effect is caused by an increasing temperature, and the action is found to be very regular. Another trap acts similarly by the expansion and contraction of ether contained in a sealed vase. All traps are in a greater or less degree troublesome, and their use is avoided in a system now largely adopted. In place of cast-iron pipes of 4 inches in diameter, wrought pipes of about 2 inches in diameter are employed. One end of each range of piping is connected to the steam space of the boiler, and is nearer (following the circuit of the pipe) to the highest point of the range, while the other end of the range is connected to the water space of the boiler. The pipes, where not required as radiators, are smaller than elsewhere. This arrangement gives much less trouble in obtaining uniform results than the former one, but is less durable.

All outlet pipes in the works ought to be conducted into one tank in some conspicuous part of the yard. This applies to

outlets from heating apparatus, cylinder cocks, drains from steam supply, mud cocks of boilers, safety-valve drips, water-gauge fittings, &c. Defective fittings are thus promptly shown, and the flooring and walls kept more sightly than with the usual promiscuous arrangements.

Transmission of Motion.

The fly wheel gives motion to a pinion about 6 feet in diameter, making one hundred and five to one hundred and twenty revolutions per minute, and staked on the second-motion shaft in a way similar to that in which the fly wheel is fixed. This shaft is usually carried in angular pedestals, and is placed in the same horizontal plane as the chief line of shafts, with a view to direct driving by simple bevil wheels. The engine is often erected with its crank-shaft centre on the same level, but frequently 5 feet or even 10 feet lower. As the shafts for the upper rooms are in the same vertical plane, one upright shaft, placed directly opposite the series, suffices to drive the whole, and only one pair of bevil wheels is required for each story.

The form of teeth in the wheels is in the last degree arbitrary. Each shop possesses a different rule, and to some extent individual workmen exercise influence over the shape of the tooth, often according to the fancy of the hour. The general law, that the normal to the common surface of the teeth described through the point of contact of the teeth, in any position, in any pair of wheels, should pass through the pitch point, is quite unknown to the mass of wheel makers. Doubtless the wisest course is to use the closest approximation to the cycloidal form. That is possible by means of arcs of circles; but is not easy of performance without the use of two arcs of circles for the face of the tooth, though one is sufficient for the root. Workmen are not to be relied upon for following instructions absolutely in such a case.

Professor Willis's form gives good working results, but involves the use of angles, which diminishes its value. Workmen are accustomed to employ some given radius for both roots and faces, and to fix the centre from which the root is described on the pitch circle, while the centre from which the face is described is fixed at a definite distance below the pitch circle.

A system has been in use for some years with successful results, which corresponds more nearly with the ordinary and simpler method just mentioned than does Professor Willis's. It was devised by Professor Smith. The teeth described by it

are slightly superior to those of Willis's on the face, which is the most important, while the accuracy of the roots (compared with a true hypercycloidal curve) is about the same. The system has been applied to wheels of various pitches, diameters, and ratios, spur and bevil. Wheels of nearly equal diameters are more usually found to work together, without actual inconvenience, than pairs which differ largely, or have a high ratio. The evils of defective form culminate in the case of a rack and pinion, as may be seen on a planing machine, in the reproduction on the work executed of the pitch of the rack. In this system the radius of curvature employed in describing both the face and the root = pitch $\left(1 - \frac{4}{u} + \frac{5}{u^2}\right)$, the root being described from a centre on the pitch circle, and the face from a point below the pitch circle, at a distance equal $\frac{\text{pitch} \times \left(5 - \frac{90}{u} + \frac{500}{u^2}\right)}{32}$. Wheels thus developed are interchangeable. This is chiefly advantageous in spur wheels, but also occasionally in bevil wheels, when shafts form acute or obtuse angles with each other. In bevil wheels, the virtual numbers must be taken. This may be done either by the development of conical surfaces normal to the pitch surfaces, and completing the circles, or by the formula $\left(\frac{u \times \sqrt{u^2 + u^2_1}}{u_1}\right)$, in which u = number of teeth in the wheel under consideration, and u_1 = number of teeth in its fellow. This applies only to wheels revolving on shafts at right angles to each other. In other cases the best way is to obtain the virtual radius at once by development, and thence the virtual number of teeth. The above expressions for the radius for rounding, and for the distance below the pitch circle, may be reduced to a table or to an ordinary diagram scale or direct measurement.[1]

Wheels which are well made, but with defective form of teeth, when set to work produce an equal, continuous, rumbling sound, varying in intensity and pitch according to the degree of divergence from a correct form, and to the number of teeth in contact per minute, or per second. Wheels are made of cast iron, moulded by machine or from a pattern. From a new pattern, divided on a good wheel-cutting machine and securely constructed, the best castings are produced. Machine-moulded wheels are much better

[1] This method has since been improved by the originator, but the details are not to hand.—G. W. S.

than those produced from a pattern which has been stored sufficiently long to become distorted, and with all wood patterns this is only a question of time. Wheel-moulding machines are exposed to great wear and tear; therefore they should be frequently subjected to the most stringent tests for verification of accuracy. Notwithstanding the utmost care and skill that may be exercised in the manufacture of wheels, there is frequently found to be one tooth, or more, of greater thickness than the others; this is usually trimmed off by pitching and chipping. If allowed to pass without adjustment, a blow is caused at each revolution. If its fellow possesses a similar defect, the severity of the blow is increased when the two come in contact. This is a frequent defect, for which the only remedy appears to be, to finish the wheels by machine. It is often most prominently displayed on wheels which are otherwise good.

The pitch and diameter are usually decided by rule of thumb, combined with experience. The annexed table (page 258) has been found serviceable in determining the diameter of the shaft, the pitch of the wheel, the indicated HP., and the number of teeth, after some of the details have been settled. In this table, the first horizontal line gives the diameter of the shaft; the second the HP. values for separate diameters. The proper shafting value, multiplied by the number of revolutions per minute, gives the actual HP. capable of transmission by the shaft, if made from reasonably good iron and in ordinary steady work. The first vertical line gives the pitch of the wheels; the second the pressure in lbs. (safe working load); the third the relative HP. values, the width of the teeth being assumed to be equal to the pitch $\times 2\frac{1}{2}$. To obtain the indicated HP. capable of transmission by any wheel, the corresponding number is selected from the table, then multiplied by the number of teeth in the wheel, and the product multiplied by the number of revolutions per minute.

If the necessary diameter of a shaft and the pitch of wheels to drive it be decided upon (assuming the work to be undivided), the necessary number of teeth may be found in the table at the intersection of the two columns. If the pitch be two-thirds the diameter of the shaft, the number of teeth is found to be fifty-seven, which is generally a good proportion to employ. Many special cases arise in which it is admissible or necessary to depart from the proportion shown in the table, but even in such cases the table is useful for reference.

In order to reduce the pressure per square inch on the larger bearings to a sufficiently low point for safe working, it is often

Diameter of shafts ..			Inches. 2	Inches. 2¼	Inches. 2½	Inches. 2¾	Inches. 3	Inches. 3¼	Inches. 3½	Inches. 3¾	Inches. 4	Inches. 4¼	Inches. 4½	Inches. 4¾	Inches. 5	Inches. 5½	Inches. 6	Inches. 7	Inches. 8	Inches. 9	Inches. 10
Wheels.		I. HP. Values. Shafts.	0·0987	0·1406	0·1927	0·259	0·33	0·4238	0·5293	0·651	0·79	0·9477	1·125	1·3231	1·5432	2·054	2·6	4·2345	6·3299	9·0	12·3456
Pitch.	Pressure.	Wheels.																			
Ins.	lbs.		Numbers of teeth in wheels.																		
1	291	·000736	134	191	262																
1¼	454	·001436	69	98	134	180	232														
1½	655	·002481	40	57	78	104	134	171	213												
1¾	891	·00394	25	36	49	66	85	108	134	165	200	240	285								
2	1,164	·005882	17	24	33	44	57	72	90	111	134	161	191	225	262						
2¼	1,473	·008378	12	17	23	31	40	51	63	78	94	113	134	158	184	245	317				
2½	1,819	·011488		12	17	23	29	37	46	57	69	83	98	115	134	179	232				
2¾	2,201	·01529			12	17	22	28	35	42	52	62	74	87	101	134	174	277			
3	2,620	·019854				13	17	21	27	33	40	48	57	67	78	103	134	218			
3¼	3,074	·02524					13	17	21	26	31	37	44	52	61	81	105	167	251		
3½	3,566	·031525						13	17	21	25	30	36	42	49	65	85	134	201	285	
3¾	4,093	·03877							14	17	20	24	29	34	40	53	69	109	163	232	
4	4,658	·047056								14	17	20	24	28	32	44	57	90	135	191	263
4½	5,895	·067023									12	14	47	20	23	31	40	63	94	134	184
5	7,277	·09191										10	12	14	17	22	29	46	69	98	134
6	10,480	·15882														14	17	27	40	57	78

necessary to enlarge the bearings to a greater diameter than that absolutely essential for the transmission of power. This must be decided mainly from experience, but the requirement is only local, the diameter of the shaft being usually reduced by tapering before reaching the next bearing.

It may be observed that the pressures given as permissible in the higher pitches are greater than 400 lbs. per inch in width, as decided by the late Sir W. Fairbairn.[1] The accuracy of the table is, however, often and independently corroborated, and it agrees closely with ordinary practice. Much greater durability is attained in such wheels by increasing the width of the tooth when the foundations are thoroughly secure, and the bearings are prevented from wearing much or unequally. Frequently such wheels are, through carelessness, allowed to bear on one side only, in which case the increased durability conferred by increased width exists only in imagination. For this reason chiefly, the present tendency is to reduce, rather than to increase, the width of the tooth. This tendency on the part of workmen to allow all wheels to drift into an unsatisfactory state of adjustment is often observed. As a rule, it is more mischievous in spur wheels than in bevil wheels, owing to the fact that the latter are more easily adjusted, and are therefore often attended to, when the somewhat more difficult operation of adjusting spur wheels would be avoided. For the reason just given, it is usually unnecessary to draw any distinction between spur and bevil wheels in using the table. If wheels and shafts are exposed to frequent or severe shocks, or are worked unsteadily, it is wise to increase the strength of each, still maintaining the same relation between them.

Where an approximate ratio in a pair of wheels is sufficient, it is wise to add a "hunting tooth," unless the numbers of wheels are already prime, as causing more steady work. Too much reliance is laid on the value of wheel-moulding machines, and the hunting tooth is considered to be unnecessary.

The ends of the teeth of bevil wheels were formerly of spherical form, described from a centre at the intersection of the centre lines of shafts, but at present they are conical, and normal to the rolling surfaces or pitch cones. This is more convenient in construction, whether for pattern or machine-moulded wheels, and produces the same result. Wheels were devised thirty years ago with the roots strengthened on the non-working side, to prevent breakage by shocks. These have been recently revived and patented, great

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lv., p. 405

advantages being claimed over the ordinary form in respect to the working load. Such claims may be justified in wheels subjected to severe and repeated shocks; but with steady work, teeth whose working and idle faces are well-shaped and similar, are found to wear away on the working faces before breaking. In ordinary work the improved form has no effect whatever till the wheels become partially worn, and may be said to add a fictitious life to them.

In small wheels, it is advisable to dispense with arms, and to substitute a continuous plate. This causes the resulting wheel to be more circular in form and rather more sound. If machine-moulded wheels are thus arranged, their cost is somewhat reduced; both kinds are shown in the figures.

Heavy wheels have their bosses split in casting, to prevent the breakage of the arms by contraction. The boss is then surrounded by a strong wrought-iron hoop on each side, to prevent bursting or springing in driving the keys. Similar hoops are often added when the boss is not split, as additional safeguards, in the case of wheels and pulleys. The pulley shown in section in Fig. 44, Plate 3, is prepared to receive such hoops.

All shafts which carry toothed wheels ought to have bearings on both sides of each wheel where possible. Any arrangement by which the wheel is between the bearing and the end of the shaft should be avoided, unless the shaft is specially strong. Toothed wheels, unless in unfrequented situations, are covered by cases of sheet iron, formed to fit closely, and so to prevent the scattering of grease and other matter from them.

Toothed wheels are occasionally used to connect two parts of a shaft which form a small angle, each with the produced centre line of the other one, and which are usually regarded as one continuous bent shaft. Another means to the same end consists in employing a pair of claw couplings, whose driving surfaces are portions of plane surfaces, traversing the axis of the shaft. These are useful for rough slow work, but otherwise must be condemned, as the communicated motion is very variable. Hooke's joint, when well proportioned and constructed, ought to be as nearly perfect for such a purpose as any other method, but it is seldom used except in small work.

Shafts 4-inches in diameter and upwards are turned from forgings; those of smaller diameters are turned from rolled bars, both being polished throughout, except where covered by wheels, couplings, &c. Large wheels are usually fixed by four keys, as before described, the shaft being bossed to a larger diameter for convenience

of manipulation. This arrangement is shown in elevation in Fig. 28, Plate 5, and in the sections of many other wheels. Smaller wheels are usually bored to fit bosses, provided on the shaft and secured by one key, which fits at the top and bottom on the flat of the shaft and the keyway of the wheel. In either case, preparation must be made to slip the driven wheel out of gear so as to stop the shaft.

When many wheels are required on the same line of shaft, they are sometimes fixed on a plain parallel shaft by conical cast-iron keys (Figs. 35 and 36, Plate 5). This arrangement is subsequently described in connection with pulleys.

In ordinary practice, shafts are secured with a view to prevent longitudinal movement at the end to which power is imparted. This is done by means of one or two journals, each provided with collars on each side. If the shaft is of great length, and carries heavy bevil wheels at points more than 40 feet from these bearings, the expansion and contraction caused by atmospheric changes become very troublesome. In such cases, other bearings are provided near such wheels, and an expansion coupling arranged in some convenient intermediate position. Ordinary claw couplings are sometimes used as expansion couplings, but the more usual form is a solid cylindrical coupling, into the bore of which the end of each shaft projects to the centre of the length. One end is then keyed securely, and the other is provided with two keys, secured in grooves on opposite sides of the shaft. The shaft and keys are made to fit accurately but easily, allowing for expansion and contraction.

The diameters of the shafts may be obtained from the table, when the speed and H.P. are known. They are usually somewhat greater than are strictly required, having reference to ultimate strength alone. By this means excessive torsion is avoided, which otherwise forms a serious evil in the employment of long shafts of small diameters. The shafts are reduced by small steps; often the consecutive lengths differ in diameter by only $\frac{1}{8}$ inch, and usually by $\frac{1}{4}$ inch. As the disposition of the machinery is permanent, the number of different sizes may be much larger without inconvenience than where the arrangements are liable to frequent alteration.

The separate lengths of shafting are generally from 20 to 30 feet long; they are secured together by solid cylindrical couplings, which are turned on the outside and bored to fit the ends of the shafts. The end of each shaft reaches to the centre of the coupling, and the two are secured by a key, either continuous or divided

in the centre of length. The ends of the shafts are turned off square, the half-lap coupling being now discarded. This coupling is the simplest that is made, and if the ends of the key are properly finished off, it presents no projection when running.

Several systems of adjustable couplings are in use, and appear to answer well, but they are more complicated, and none have so neat an appearance as the solid one; neither can they claim any important advantage in their adjustability, except with shafts that ought to be rejected on account of careless turning. Sellar's coupling, and one or two others, however, by changing the bushes, can be adapted to the ordinary small changes of diameter of shafts, without reducing the larger to the diameter of the smaller one. Their chief advantage, however, lies in the fact that they dispense with the use of the key sunk into the shaft (or, at least, they reduce its importance greatly), also with the bosses thereby rendered necessary, on the adjacent ends of shafts. Again, by dispensing with bosses the majority of shafts may be run through a stretching machine, thus dispensing with hand stretching.

The couplings are placed as close to the bearings as possible, and on that side of the bearing which is farthest from the driving point, from whatever source the power may be derived. The chief reason for this is, that if any part of a shaft requires to be stopped, the proper coupling may be taken off, and the shaft will still be supported throughout the running part. Also because the shaft is generally secured against longitudinal movement at the driving point; then, if it becomes necessary to disconnect any single length of the shaft, the facility of longitudinal movement is a great convenience. The addition of an extra pulley in a bay which contains a coupling may by this means be performed without any hoisting of shafts, which would be impossible with a reserved arrangement.

All shafts are now erected overhead; in some old works, a single shaft was arranged to serve two floors. The fire risk absolutely prohibits such an arrangement in modern factories. Very few machines in such works require the use of a countershaft, being driven directly from the line shaft, and hence the question of length of belts does not arise to cause the underground system to be desirable.

The driving pulleys are fixed to the shaft almost invariably in the same manner. A conical hole is bored in the boss of each pulley, whose smallest diameter is sufficiently large to allow the pulley to pass the bosses on the shaft. This hole is fitted with a bush which is bored to gauge fitting the shaft, and split longitudinally in three equidistant places; the three pieces so

produced are driven into the pulley boss, being held by friction alone; they are fixed and removed with great facility. If necessary, the pulley may be taken to another shaft of nearly equal diameter, by merely providing a fresh set of these conical keys of different bore to fit the second shaft. Readjustments of the machines or the renewal of the belts often necessitate slight removal of the driving pulleys, and this is easily done when fixed as described. Fig. 36, Plate 5, shows the application of this fastening to wheels, and Figs. 45, 46, and 47, Plate 3, to pulleys.

Every piece mounted on a shaft ought to be balanced separately, more especially if the speed exceed one hundred and thirty to one hundred and fifty revolutions per minute, or the revolving pieces are comparatively of large diameter. When balancing is attempted, it is often by a weight sufficient for a standing balance, added anywhere when the pulleys or other details are in place. Neglecting the possibility that the position of details may be greatly altered, the whole arrangement is ineffective, because the balance must be restored in the same plane of revolution that contains the disturbing cause. Every running part ought therefore to be balanced in itself as far as practicable.

The bearings of shafts are at distances of 10 to 11 feet from centre to centre. They are usually fixed, that is, without facility of self-adjustment. Their length is equal to twice the diameter. They are provided with top and bottom brasses, or bottom brass and cast-iron cap to fit the shaft, and bored along with the bottom brass. The iron cap to fit the shaft may be replaced by a shell cap, containing a recess to hold tallow for use in case of accidental heating of the bearing. An ordinary flat pedestal is shown in Figs. 47, 48, and 49 (the apparatus on the side is subsequently referred to). It may be noticed that one end is cut away to shorten the base, in which case the cap bolt is provided with a collar, and nuts at each end, to act as cap and holding bolt; obviously, this can only be done when the lower end of the bolt is accessible for tightening the nut or nuts. The holding bolts are often arranged with the heads in T grooves, as shown in Figs. 28, 29, and 30, Plate 5. This is when the lower side of the plate is not disposed so that a bolt can be passed through from the reverse side; or, in other cases, to prevent the drip of oil which takes place with thoroughfare holes in a horizontal plate. Strips are often cast on the sides of brackets and other pedestal preparations, to prevent the flow of the oil as much as possible after it has left the bearing. These are useless when the bolt holes pass through the plate, and in any case a better arrangement is to cast an elongated dish on each side of the pedestal.

Loose oil dishes, with flat pedestals, are seldom employed, and never succeed well.

In the best practice, pedestals, and the surfaces on which they lie, are planed, but many are still bedded with a piece of soft wood between the rough cast surfaces of the pedestal and its plate. At each end of the pedestal, a snug is cast on the plate, preventing the motion of the pedestal; a small space is left between the pedestal and the snug, allowing a small adjustment (the bolt holes being arranged with the same view), and the space is afterwards fitted with a float of beech or iron. This space and snug are shown in Fig. 49, Plate 3. When the pressure is always tending to cause the pedestal to move towards one snug, the other is often omitted, more especially if the space is limited.

Wall boxes are often required for the support of the bearings of shafts, and to form and preserve openings in walls where required for the accommodation of wheels, &c. Examples are shown in Figs. 31 to 42, Plate 5. The best practice consists in arranging and providing the wall boxes as the work proceeds, then laying the stones beneath the position of the boxes as shown, and disposing the boxes so that the wall may be built up to every side; the covering stones are then placed on the top of the boxes as shown. Wherever practicable, wide outside flanges must be left on each side of the walls as extra preventives against movement when working. This cannot be so conveniently done if the boxes are inserted after the building of the walls. In any case, it is impossible to bestow too much care upon the secure execution of the work.

Small wall boxes are employed as shown in Figs. 34, 35, and 36, for the attachment of simple brackets, allowing an easy adjustment of the height of the centre of the shaft. They are best arranged to pass through the wall with a flange on each side, but are often stopped short, as shown in the Figs. 34 and 36, for the sake of appearance. When boxes are not provided with outside flanges on both sides, the difficulty of secure fixing increases with the decrease of the depth projected into the wall. Small boxes are shown in Figs. 38 and 39, whose office is to preserve the form of the opening made in the wall for the reception of a shaft or other object. All boxes which give a clear opening through a wall are provided with internal flanges, to which wrought-iron plates are bolted, forming a fire-proof barrier. Effective means ought always to be taken to prevent the smearing of the walls by the oil which runs off the bearings.

A small bracket is shown in Figs. 47, 48, and 49, Plate 3, for the

ɔption of a single flat pedestal. It is bolted to the face of the l, and the snug on the back is inserted in the wall to assist the ts in carrying the weight. It is almost impossible in practice nsure that the pedestal bed of a bracket of this class shall prove be of the correct height. This class of bracket is therefore nited to the attainment of first-class work.

ide pedestals are bolted to pillars specially prepared, or to some ır vertical plane surface. A pillar with side pedestal, and ying an upper floor, is shown in Figs. 50 and 51. Side pedestals fitted with brasses, or bottom brass, and solid or shell caps, in same manner as flat pedestals.

The foot of an upright shaft is steeled, or has a short piece of l welded to it. It is surrounded by a brass bush, which is ıetimes whole, and in other cases split. A plate or disc of gh brass is placed beneath the shaft to bear the weight; this e is often provided with a wrought-iron hoop, shrunk on, to vent it from splitting under pressure. A large hole should drilled in the centre of this disc, and preparation made for free entry of the oil, the utmost care being taken to ensure . A cap is provided, which forms an oil-tight joint with the ket, preventing the escape of the oil, and yet allowing free s for inspection of the shaft and brasses. The brasses are ised for withdrawal by slightly elevating the shaft; lifting ws for effecting this are provided in the first instance. Two . boxes, with the wheels, shafting, &c., pertaining thereto, are vn in Figs. 37 to 42, Plate 5, one pair of the wheels driving the ght, and the other pair driving an upper line shaft from the ght shaft. The practice is becoming general of providing parate walled tower around the upright shaft, with stages or s at each pair of wheels. In this system the footstep is ied on a massive plate, which rests on the stone and brick dation, carried up from the place at which a sufficiently solid ing is obtained. The superiority of this system is manifest. foundation is infinitely superior to any arrangement of kets, &c.; the risk from fire is greatly reduced, all openings g closed by iron doors; the facility of working at adjustments ıcreased, as the scaffolds are already fixed, and more than ordi- y secure; the bearings are kept more free from dust and other rial; in case of wheels breaking, the damage is confined to ower, the floors above and below the broken pair of wheels ırse being sufficiently stout to resist the flying fragments e mischief will be extended; the grease is also confined inside ower, and prevented from smearing other objects. The same

principle is sometimes extended to the whole second shaft, which is then enclosed in an elongated room.

Bearings which possess a facility of self-adjustment, with respect to the direction of the axis of the revolving shaft, have not met with extensive adoption in this district. They are largely adopted in the United States; one of the chief reasons being, that the buildings being lighter, and containing more wood in their structure, are not so stable as those in England. The same evil is encountered in England, though in a smaller degree, and the more frequent adoption of these bearings would produce good results. Another reason for their more extensive adoption in the States is, that the shafts are lighter, and more easily deflected by the tension put on them by the belts; this tension (being a variable, or even reversible quantity) soon destroys the bearings when not self-adjusting. The general adoption of self-adjusting bearings in the States allows the use of lighter shafting without encountering some of its chief drawbacks. But, even then, decreased first cost, and an appearance of elegance, scarcely balance greater wear and tear and a shorter life of the shafting and appointments.

The usual speed of line shafting is one hundred and twenty to one hundred and sixty revolutions per minute. This is exceeded in some rooms, where the machinery runs at a very high speed; and also in others where the machines are driven by quarter-twisted belts, to reduce the diameter of the pulleys on the main shaft, and therefore, in an equal degree, the lateral obliquity of the belts. Higher speeds than the above have been occasionally adopted, but the ultimate economy is found to be less. The outlay in the first instance is certainly less, but if the shafts are in each case rigidly proportioned to the work which is to be performed, the friction is not less, as has been assumed, because the speed must be increased in a high degree. When the diameter of the shaft is decreased, the power per revolution is decreased in a greater ratio, because the power varies as the cube of the diameter. Therefore, to transmit an equal power the reduced shaft must be driven at an increased speed, denoted by the original speed $\times \left(\frac{\text{original diameter in inches}}{\text{reduced diameter in inches}}\right)^3$. But as the radius of friction on the surface is reduced at the same time as the revolutions are increased, the moment of friction, or the velocity of the surface, is only increased in the direct ratio of $\left(\frac{\text{original diameter}}{\text{reduced diameter}}\right)^2$. The weight of the shaft being reduced in the same ratio $\left(\frac{\text{reduced diameter}}{\text{original diameter}}\right)^2$,

causes the actual amount of friction to be the same as before. But the difficulty arises, that the bolts are not adjusted to the utmost possible degree of accuracy, and the smaller shaft is in some cases required to resist the same side strain from tight belts to which its more sturdy predecessor was subjected; it therefore deflects, and if the bearings are solid, they wear out much faster than those of the larger shaft. Again, the angle of torsion varies inversely as the fourth power of the diameter (diameter^4), and this reason alone requires considerable allowances to be made on the diameters of small shafts of great length, when indeed it does not totally prohibit their use.

The line shafts are often driven by belts passing from a wide pulley on the crank shaft, and forming the fly wheel; or on the second-motion shaft, which is then driven by spur gearing, as before described. The drum or pulley in question is usually arranged to accommodate the same number of separate belts as there are of line shafts to drive, and a belt passes directly to each; or some of the more distant line shafts may be driven by the intervention of others more favourably situated. This system of belt gear, as it is commonly designated, has been the favourite one in some districts for several years, and it has one great advantage over ordinary toothed gearing in its almost absolute silence. Of course its transmitted motion is not positive, and in calculation it is wise to provide for a small amount of creeping, by giving a slightly excessive calculated speed to the line shafts; when this is done, and proper proportions are assigned, no difficulty is encountered. Cases often arise where a belt may be substituted for other and more complicated arrangements, with great success; more particularly with short-stroke high-speed engines. Notwithstanding this, its indiscriminate adoption cannot be too strongly deprecated. No general law can be given to decide its suitability or otherwise, as every case must stand on its own special merits, and be fully investigated, before any reliable decision can be given. It is impossible to give too much emphasis to the statement, that a high surface speed is necessary to the successful adoption of this system. This is not because high speed is a desirable factor when viewed alone, but because the speed increases directly with the number of revolutions, and with the radius of the pulleys, both of which are valuable factors. The work transmitted in HP. $= \left(\frac{\text{lbs. belt tension} \times \text{speed in feet per minute}}{33{,}000}\right)$, neglecting the unavoidable tension on the idle side of the belt. Evan Leigh's rule, published some years ago, is extremely trustworthy, yielding

a good working and economical result, the width of the double belt in inches $= \left(\frac{66{,}000 \times \text{indicated HP.}}{\text{length of arc of contact on the lesser pulley} \times \text{the speed}}\right)$, speed in feet per minute. The correctness of this rule has been repeatedly confirmed, both by success and by failure. An impression is current to the effect that long belts possess advantages over short belts in their capacity for work. The rule makes no distinction as to length, as no difference can exist in the case of vertical belts, and the difference, if any, must vanish as the vertical is approached. It may be noted that the angle made by the plane containing the centre lines of the connected shafts, with the horizontal plane, would claim equal attention with the distance of the centres. When the centres are near together, and the connected pulleys are of different diameters, the length of the arc of contact on the smaller pulley is decreased; this is accounted for in the rule. Short belts also require more close attention to maintain an equal and constant tension, but this only acts to a small degree. A usual speed of belting at Lowell, Massachusetts, is 1 mile per minute (say 5,200 feet) with pulleys 10 to 12 feet in diameter; with these conditions the belts are loaded to transmit 10 indicated HP. per inch in width. This is less than they would safely carry according to the above rule; but a belt as made at the present day is stronger than those made at the date of the Lowell mills. At the present time some of the Lowell belts run very crookedly, thereby proving that they do not possess the same strength throughout. The width of many belts (more particularly when replacing arrangements of other kinds) has been fixed by rule of thumb, mostly with success because decided of excessive width. In replacing toothed gearing by belting, there is occasionally a difficulty in providing sufficient room for belts of ample proportion to cope with the required work. Under these circumstances, they are often applied of meagre proportions, causing failure, more or less complete. In the case of small pulleys, it is unsafe to take any given load as a basis, because the requisite tension on the idle side cannot be readily determined. With pulleys of 3 feet 6 inches to 4 feet 6 inches this back tension becomes excessive; the power required to bend the belt around the pulley becomes also an important element in the conditions to be regarded. With pulleys of less diameter than 3 feet 6 inches, double belts should not be used, as their economy then becomes doubtful.

The most usual material for belting is leather. In the best belts it is employed in the form of strips 2 inches to 3 inches wide.

These strips are carefully jointed together to form continuous strips, the whole length of the belt; they are then stitched, pegged, or riveted, in such manner as to break joint longitudinally, the transverse joints of the strips being also separated as much as possible. In completing the endless belt in position, it would be inconvenient to make the long splicings necessary to continue the same system throughout, even if it was possible to stitch, peg, or rivet it by hand firmly enough to prevent the rising of loose ends. The ends are therefore left square, and are connected by outside metal plates; these plates are in some cases attached by taper recess-head screws, very similar to those used for wood; in other cases bolts are used, with a thin feather-edged flush head against the pulley, and the nut on the outside of piecing plate, the head being provided with spikes to sink into the belt, and prevent its rotation in tightening the nuts, or in subsequent working. The plates fixed by bolts provide a secure and convenient method of joining the two ends together; they, however, cause a slight shock on coming into contact with the pulleys; they also prevent the use of a guide or tightening pulley pressing against the outside of the belt, which would be often convenient.

In the best double belts care is exercised to ensure that the points of all splicings are directed towards the same end on both faces throughout; then the end towards which the joints are directed is arranged to follow the other when the belt is ultimately set to work. Obviously, this cannot be done on both sides of a belt of single thickness, and the piecings are set to run the proper way on the inner side, as the most important one. If a guide pulley is applied (as is often the case) to the outer side of such a belt, the corners of the splicings on that side usually begin to rise, sooner or later, and can scarcely be made secure afterwards. With narrow belts the best way is to twist the belt through one half revolution, opposite the guide pulley if necessary, causing all the pulleys to work on the same side of the belt. The longitudinal direction of splicings is shown in Fig. 52, and the cross section of belt in Fig. 53, each referring to belts of double thickness.

Belts of American manufacture are now in use in England. They are of double thickness. The longitudinal joints are neatly spliced and arranged as above described; either the two layers are in single widths or the strips are much fewer in number than in the English belts. The final joint is made by means of stout leather thongs, or laces, so that no projection exists to interfere with the use of guide or tightening pulleys, on either side of the belt as may be most convenient. A novel form of belting is

manufactured by Messrs. Aitken, of Helmshore, from cotton yarn: special looms are employed, which will make the belts of any length, width, or thickness. Hitherto they appear to answer well as main belts, but their applicability as machine belts is doubtful, unless with special prongs or strap-shifting forks. Steel belts provided with projections engaging recesses in the pulleys, are also employed; they give a positive transmitted motion, but their success remains to be proved.

All arrangements of belt driving are wasteful in power, as evidenced by the fact that longer journals are necessary than with toothed-gearing connections; this is especially the case when the only admissible pulleys are of small diameter. The supporting bearings ought to be as near to the pulleys as possible, to prevent deflection of shafts. Where the pulleys cannot be carried by bearings close to them, an arrangement is sometimes adopted which is a close approach to the self-adjusting bearings already mentioned. When the belt works in a vertical direction, the pedestals are held to a horizontal fixed plate by one pair of holding bolts to each pedestal; passing from one of these bolt holes to the other, a ridge is provided on the fixed plate or on the pedestal base, which ridge projects from the general plane of the face of the casting; or a loose strip of some material is inserted in that position (across the line or shaft in plan). The nuts of the holding bolts are then screwed down gently and locked. The pedestal will then follow the shaft when the latter is tilted up at either end a small amount from the level position. Then, notwithstanding a slight deflection, the whole length of the bearing carries the weight equally, and overheating is prevented, or stopped if not too far advanced. If, however, the heating has been at all serious, any labour expended with a view to its mitigation is usually wasted, unless directed towards re-bedding the shaft in its bearings. The reason of this is, that when a bearing brass is heated to any serious extent by friction, the bore tends permanently to assume a more concave form, as though its cross section formed a portion of a circle of smaller diameter than before; therefore, unless bored too large in the first instance, it is now too small, and nips the shaft, causing an increase of friction, which already is excessive. Many times trouble has also been caused by making the brasses of the full length (or nearly so) of the journal in the shaft. The expansion of the brass when heated is greater than that of the shaft. This is partly because the coefficient of expansion by heat is greater in brass than in iron, and partly because the brass is of less bulk and greater conductivity

with respect to heat. Both of the latter causes tend towards the same result as the first one; that is, the brass expands by heat much more quickly than the shaft. The more rapid increase of length of the brass causes it to press severely on the ends of the journal if not provided for by leaving clearance in the first instance; this action again heats the bearing still more, and the reciprocatory action continues till the brass is sufficiently shortened. Often a short time suffices for the total ruin of brasses and journals from this cause. When that occurs, the only safe proceeding is to take out the shaft, re-turn the journals, and fit new brasses.

Each pair of brasses ought, in the first instance, to be made shorter than the journal in which they are employed. This may be condemned as an unworkmanlike proceeding; but when the bearings in the same works under the charge of one man (and his time not exclusively devoted to them) may be counted by hundreds, it is easy to see that any one is liable to be overlooked at a critical moment in some period of its life. In old works, some important bearings are quite inaccessible when the shafting is in motion, and therefore in an unknown condition, but this is seldom found in new works. It then becomes necessary to adopt all simple and practicable measures whereby over-heating may be prevented. The amount of longitudinal clearance to be allowed may vary from zero to 10 per cent. In determining the amount due regard must be paid to the maximum period that the part may be expected to work at any time without attention, also to the possible effect on the connections of the shaft produced by its maximum longitudinal movement. If a shaft has no connection otherwise than by means of belts, a considerable longitudinal movement introduces no evil to compare with the good effect produced in smoothing the bearings. The fact that the first prolonged heating of the shaft and brasses causes incalculable mischief cannot be too strongly insisted upon.

Belts connecting two parallel shafts by means of pulleys whose surfaces are not absolutely cylindrical, tend to run towards the part of each pulley that is of the largest diameter. This is caused by the lateral stiffness of the belt, which leads it towards the higher side. If two shafts whose axes are in the same plane are not parallel to each other, the belt connecting them by pulleys with cylindrical surfaces will tend to run towards that part of the shaft in which they are nearest to each other. The opposite condition is usually deduced from the acknowledged fact with respect to non-cylindrical pulleys, but if this was the fact it would follow

that the action of a strap-shifting fork would be a reversed one. In a belt connection by pulleys with cylindrical surfaces, the belt must leave each pulley in the plane traversing the centre and perpendicular to the axis of the pulley with which the belt comes next in contact, whether the system comprise two, three, or more pulleys. Paying due regard to the above facts, a belting arrangement may be sometimes employed for the connection of two shafts not parallel to each other, and at different heights, with or without the assistance of one or more guide pulleys.

The pulleys employed with belts are usually of cast iron, carefully turned, polished on the surface, and balanced. Occasionally, in wet situations, they are applied without turning on the surface; and when carefully made and balanced there is no reasonable objection to such pulleys. Some difficulty is encountered in casting them sufficiently true all round without showing the mould parting, and with constant amount of cross or lateral curvature. Disc pulleys are more reliable as to form than the usual arm pulleys, but are inadmissible for large diameters.

Wrought-iron pulleys have been largely made, most frequently in halves, with the rim jointed by lapping and passing screws through. These screws are sometimes troublesome in failing to hold the two parts securely together, and would probably be replaced by rivets with advantage.

Smaller pulleys for driving the separate machines are made of cast iron, with cylindrical faces when required to accommodate a shifting belt, and convex for a belt which is not shifting. A pulley for driving a light line of shafting is shown in Figs. 43 and 44, Plate 3.

Another system of connection is by ropes, usually of hemp, but occasionally of cotton. The conditions of application are nearly the same as for belting. The two pulleys are provided with rims of much greater thickness than for belting; V-shaped grooves are in the first instance cast, and afterwards turned with a greater or less degree of accuracy. The rope presses against each side of the groove with a kind of wedging action, taking firm hold of the same; the bottom of the groove is turned out to a circle of a radius smaller than that of the rope, with a view on the one hand to avoid the possibility of the rope touching the bottom of the groove, and on the other hand to reduce the depth of the rim. This system is not making so much progress as it would do if reasonable care were taken to ensure the same working radius for each rope in the separate grooves. Pulleys are occasionally to be found the turning of which is of the lowest class, while the utmost care and skill are

ecessary to success. A convenient test for the accuracy of the rooves is to fit a card or thin piece of wood to one groove quite losely, then to lay a straight-edge across parallel to the shaft, nd mark off. The gauge may be applied to another groove and gain marked. If in the second and subsequent grooves the sides re a close fit and the marks coincide, the pulley may be said to be atisfactory. Many pulleys are far from answering to the above ests, as the card does not fit the grooves in a similar manner, and ndicates a difference in the working depth. Because the rope fits o the sides instead of the bottom of the groove, it sinks more or ess into the groove, just as the cross mark on the card does. Now he lineal amount of rope paid off varies as the radius $\times$ 6·2832, nd varies in the different ropes by an amount equal to $m \times 6 \cdot 2832$, where m = maximum difference in the depth to which the gauge nark (and therefore the rope also) descends; in an exactly equal egree does the amount picked up on the other side of the pulley iffer in the separate ropes. Ultimately, however, the amount icked up in each groove and paid off on opposite sides must be qual, unless the groove in the fellow pulley which engages the ame rope is similarly proportioned, or unless (as is rarely the ase) the errors are tolerably compensated by each other. The ineal amount can only be equalised by one rope being more tretched than the other in transit between the pulleys, and being imultaneously slackened on the opposite side. This evil becomes o large at times that the removal of some ropes actually relieves he remaining ones.

It is also advisable to obtain the full number of ropes for the onnection of any pair of rope pulleys at once, thereby ensuring hat they will be all of the same diameter. Grooves are usually rovided in the first instance for a greater number of ropes than re at once applied, the deficiency being made up as the work ransmitted increases. If four ropes are provided in the first nstance, while grooves are made for six ropes, the four ropes nevitably stretch during the first period of work, correspondingly lecreasing in diameter; if from one spinning, and with well-pro-ortioned pulleys, they will gradually get into good working order. t may ultimately be found that another rope is required. This ay (possibly) be obtained of an initial diameter equal to the ltimate diameter of the former ropes; after a short period of work ; will be found to be stretched to a diameter smaller than the thers, with the attendant evils as described. If, instead of this, he rope be obtained of a diameter equal to the diameter of the rmer ones before application, and of the same texture, &c., the

difference will arise during the first part of the working life of the supplementary rope, while it may possibly become practically similar to the others, suffering more or less severely in the process.

It is obvious that if the grooves are correctly formed, and the pulleys of sensibly equal diameter, another rope might be added at any time, of any diameter that the grooves would accommodate; as an equal difference in the radius would result in each pulley, no inconvenience would result. But usually there is a great difference in the diameters, for often one pulley is about thrice the diameter of the other. The grooves are arranged so that, in section, the sides make an angle of 45° with each other, more or less, according to the practice of different engineers. It may prove desirable to make this angle more acute in pulleys of small diameter, and less acute in pulleys of large diameter. By that means the rope would be more securely held on smaller pulleys, where the tendency to slip is greatest. The power consumed in forcing the rope into the groove would also be reduced in the case of a large pulley, with the wear and tear attendant on the process, the acute angle being in that case not necessary in the same degree to prevent slipping. By this means, however, the inconvenience encountered in adding ropes would be aggravated.

The splices of ropes, however skilfully made, prove either thicker or weaker than the body. In the former case they cause an unsteady transmission, while in the latter they break before the rope is worn out. Rope-driving arrangements appear to be most satisfactory when a number of ropes amply sufficient for all probable requirements are provided in the first instance, carefully watched, and defects promptly attended to. In other cases it is difficult to ensure an equal strain upon each separate rope, even with good pulleys.

The rope-driving principle, has advantages over belting in first cost, and in greater range of applicability to non-parallel shafts without the use of guide pulleys; otherwise their merits are nearly equal when well proportioned and constructed.

Almost all machines are provided with fast and loose pulleys for convenience in stoppage and starting. Long machines which require frequent stoppage are provided with a rod throughout the whole length, so as to be promptly stopped or started from any part. Long machines with few stoppages have a lever at the driving end. In these machines the loose and fast pulleys are contained in the machine, and provision is sometimes made for automatic stoppage when certain contingencies arise. The loose pulley does not bear directly on the shaft, but on a cast-iron bush (which is

held by a set screw) bored to fit the shaft, turned on the outside to fit the eye of the pulley, and furnished with a collar to retain the loose pulley close to the fast pulley. This cast bush fulfils several offices; two surfaces of cast iron wear better together than cast and wrought iron; the bush is easily replaced by one of larger diameter, when it or the pulley becomes worn; the bearing area is increased, and the wear thereby reduced. A pair of fast and loose pulleys are shown in section in Fig. 46, with plate webs for neatness and cleanliness.

Machines which absorb much power, and therefore require heavy belts, or which are stopped on few occasions and for long periods, are provided with a different modification of the loose pulley. Instead of being placed on the shaft which is driven by the shifting belt as above, they are placed on a line shaft close to a bearing (shown in connection with an ordinary flat pedestal in Figs. 47 and 48, Plate 3). The pedestal, whether a flat or side one, is provided with top and bottom brasses and cast-iron cap. On that side of the pedestal which is nearest to the pulley, and cast along with the pedestal, is a semi-boss projecting sufficiently to pass through the boss of the loose pulley, a similar semi-boss on the cap completing the hollow cylindrical boss which on the outside fits the bore of pulley, and its inside is cast sufficiently large to clear the shaft. Obviously, the screwing down of the cap to take up the wear of brasses disturbs the cylindrical form of the projecting boss, but as the loose pulley never revolves, except during the transfer of the belt from one pulley to the other, there is no necessity for an accurate fit. For the same reason, a set screw with rounded point projecting into the bore of the pulley, and working in a groove of semicircular section, turned in the boss, furnishes means sufficient to prevent longitudinal motion. The advantages of this arrangement are: the belt and loose pulley are absolutely at rest when not required in actual work, thus saving much wear and tear. The shaft being relieved of the tension of belts does not encounter so much friction, and wear and tear of the bearings are reduced. A slight disadvantage exists in the fact that the belt must be set in motion by hand, when the machine requires to be started, in some cases the assistance of a second man being required; its advantages under the circumstances mentioned, however, overbalance its defects, and the arrangement is largely adopted.

The foregoing account is applicable to a large proportion of the best works in the district, and may be said to be a description of what has become the typical practice in such works; very little tendency to abandon the lines denoted being found at present or

likely to be so for a long time. The chief modifications take the shape of heavier working parts, greater protection of moving parts, increased accessibility throughout, and better design. Under the last head is chiefly included the abolition of sharp corners, whether re-entrant or prominent, and more especially where great strains must be resisted, as in cast-iron framing and the journals of shafts, crank pins, &c. Another point, in which great improvement has been made, is in the foundations, of which an instance has already been given in upright shafts, and in towers carrying gearing.

In all works the desirability of a ready means of stopping the line shaft in any part of any room is strongly felt. Such a convenience would often provide the means of saving life and property by its prompt use. Clutches, and arrangements for throwing the wheels out of gear, have been adopted, but not largely. Apparatus for the prompt stoppage of the engine has been often adopted in small works for special purposes, and would probably extend greatly if it were not because of the fear of the abuse of such a system. An almost absolute system for the detection of the place from which a stoppage is effected, can be arranged simply by means of paper seals, and it is somewhat difficult to understand the apathy manifested on this point.

The question of hoisting and transit of materials may perhaps be suitably introduced here. The usual arrangement for conveying material from one floor to another is by a box hoist, working up and down a square brickwork isolated well, round which, in many cases, the staircase winds; with a view to safety, the two are sometimes arranged separately. Shafts for dust and ventilation must usually be provided, and by employing the staircase well for one of these purposes there is no necessity for a loss.

The hoisting motion is best obtained by a worm wheel and worm, driven by open and crossed belts for up and down direction. On the worm-wheel shaft are three grooved pulleys, over which are passed separate ropes, attached at one end to the hoist box, and at the other end to a balance weight. The use of three ropes is extending; the centre one is left slacker than the two outer ones, and as the whole are in sight from end to end, the arrangement is safe without being complicated. An important precaution to be observed consists in covering the top of the hoist box with stout boards, for protection from falling bodies.

A useful hoisting arrangement for bales, &c., requiring, however, a cat head, consists in providing a shaft which is kept in motion throughout the time occupied in hoisting operations. A

shaft is provided parallel to this one, with rope barrel and large turned cast-iron pulley set opposite a similar but smaller one on the first shaft. The pulley on the barrel shaft rests against a wood brake block, so situated that the load prevents the pulley from leaving the brake block. When the large pulley rests against the brake block the shafts are about $\frac{3}{8}$ inch too far apart for the pulleys to come into contact; but the end of the barrel shaft which carries the pulley is arranged so as to be moved towards the running shaft by means of a bell-crank lever, which causes the two pulleys to come into contact, and the one drives the other. The lever is worked by a cord passing over a pulley, and is raised by pulling the cord, causing the pulleys to come into contact and the load to be hoisted. On releasing the cord the lever drops, and the pulley comes into contact with the brake block, which action is also assisted by the action of the load. By easing the pulley off the brake block the load is lowered more or less quickly according to the degree of separating force. A more elaborate form of this hoist is made by Messrs. J. Barker & Co., Limited, Oldham. It is arranged so that by variously placing one handle, the load may be raised, lowered, held, or traversed in either direction along a beam, or rather suspended beneath the beam. The great convenience of this arrangement is obvious.[1]

The use of traction engines is extending as local carriers, subsidiary to railways. In some cases, they are superseding existing railways where the markets are not more than 20 miles distant. Some complaints are made against the occasional production of smoke, and the discharge, after a period of idleness, of the soot which has accumulated in the chimney. Much of the country in this district is far from presenting a level surface. As a consequence the traction engines are often stopped on an incline, when it becomes difficult to take one wagon to the summit if heavily loaded. There is therefore much slipping, boulders and splinters of stone being freely used, in a manner similar to that in which sand is used on railways. The inevitable result is, that great wear and tear ensue, particularly with the wheels. The hauling apparatus recently devised and applied by Messrs. Aveling and Porter will probably be largely adopted in such cases.

The communication is accompanied by several drawings and tracings, from which Plates 3, 4, and 5 have been engraved.

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[1] *Vide* "Engineering," vol. xxi., p. 389.

No. 1,646.—"On Keeping Irrigation Canals Clear of Silt."[1]

By Robert Burton Buckley, Assoc. M. Inst. C.E.

There are four methods by which it is possible to exclude more than a desirable proportion of silt from entering an irrigation system: (1.) By works in the river, which will clear the water before it enters the canal. (2.) By so constructing the head sluice of the canal that only water bearing the desired proportion of silt is admitted. (3.) By constructing a depositing basin near the head of, and in, the canal itself, to be cleared either by dredging or by hand labour; or, what is practically the same thing, by making two supply channels from the river to the canal, one to be used while the other is being cleansed. (4.) By constructing a double row of sluices, with a settling tank between, so arranged that the water is drawn off from the lower row carrying the desired amount of silt, and so designed that the deposit in the tank can be flushed back again into the river.

These systems are, of course, applicable under different circumstances. The first can be rarely used, and only when the local conditions are suitable. As, for example, where the bed of an inundation canal is perhaps 8 feet or 10 feet above the level of the bed of the river, and which canal is therefore only supplied when the river is in flood. In such a case, if a position for the head of the canal can be selected behind an island covered with brushwood, the top of which is perhaps a little below, or even slightly above the high flood level, it may be well worth the cost to make an artificial connection between the head of the island and the main land, so that all the water entering the canal will first flow through the bay, formed between the island and the main land, entering that bay from below. The velocity of the water in the bay will thus be diminished; the water will deposit silt in the bay instead of carrying it into the canal; and if the bay be a large one the canal may work for many years without its bed silting up.

The same principle can be employed on large irrigation schemes, by altering the methods now generally adopted in these works. The almost invariable arrangement is, that the weir which stretches across the river, at a height of from 8 feet to 15 feet above the bed, is cut by two sets of under sluices, which are purposely set

[1] Abstract by the Author of an Original Communication on "The Proper Construction of Irrigating Channels, &c.," accompanied by nine sketches.

as close as possible to the head sluices of the canal immediately above the weir; the floors of the head sluices and of the under sluices being at the same level. The under sluices are placed in this position so that silt may not accumulate in front of the entrances to the canal, and thus impede the free entrance of boats to the lock and of water to the canal. This object is attained by opening the under sluices during floods, thus drawing down a rapid stream immediately in front of the openings to the canals, which scours the channel, and removes any deposit that may have accumulated. At the same time that this action of the under sluices clears the approaches to the canal, it causes the canal to be more deeply silted, for the higher velocity produced by the scour of the under sluices removes an extra quantity of silt from the bed of the river, and it is from this rapid and silt-bearing stream, impinging directly on the head sluices, that the canal is supplied. But if the weir were constructed with a double set of under sluices at each end, one set being in the line of the weir, and about 200 feet from the river bank, and the other set some distance lower down the river, but connected to the upper set by a flank wall parallel to the river bank, and if the off-take of the canal were placed immediately above the lower set, the stream flowing to the upper set would not pass in front of the off-take to the canal. The silt-bearing water would pass through the upper set of under sluices with full velocity, while that portion of the river destined for the canal would have its velocity checked immediately opposite the flank wall, and would deposit its silt to a great extent before it reached the head sluices of the canal. To sweep away the silt which would be deposited between the weir and the head sluices, it would be necessary to close the upper under sluices and to work the lower ones. This plan would be rendered most effective by closing the head of the canal for a few hours every week, while the lower under sluices were opened, so that the channel might be kept clean without allowing any silt-bearing water to have access to the canal.

In almost all cases the head sluice of a canal is formed by rows of single shutters sliding in vertical grooves, so that water is always first admitted to the canal from below the shutters, that is at the level of the sluice floor. If the sluices were constructed so that the water was drawn from the top instead of from the bottom of the river, much less silt would be carried into the canal. In rivers which rise moderately, it is best to have a single opening in each vent, covered by three or four shutters sliding in a vertical groove; and each of these shutters should have independent opening gear. In rivers liable to floods rising 30 feet it is necessary to

have, in each vent of the sluices, several openings at different levels, each opening being fitted with an independent shutter, so that water can be drawn off at different levels as the flood rises or falls. This way of dealing with the silt can at most be but partially effective; but there are some rivers, carrying a small amount of silt, to which this system may be applied with sufficient effect to render the clearance of silt from the canal unnecessary.

The third method is frequently adopted in Indian canals. The first ½ mile of the canal is excavated with a base sufficiently large to cause a great diminution of velocity; the silt is deposited during floods, and excavated when the canal is closed during the summer; or perhaps it is dredged out at a cost even more excessive than that of excavating it by hand.

The fourth method is peculiarly suitable for rivers with a rapid fall. It is also most desirable where a canal runs alongside of the river for some distance before branching off into the country. If this method be adopted, the channel for the first ½ mile or so must be of such capacity that the velocity of the water in it, when carrying the full volume required for the canal, shall not exceed that which will allow of the deposit of the matter in suspension; so that the water, when it reaches the end of this length, shall contain only that proportion of silt which the channels below are arranged to convey to the fields. At the end of this broad channel a sluice will have to be built to carry the full discharge required in the canal with little or no head upon it. The head sluice on the river bank must be designed so that, with only a moderate flood in the river, a sufficient quantity of water can be introduced into the canal to generate a velocity of 3 feet to 4 feet per second in the broad reach, the flushing sluices leading back from this reach to the river being arranged to discharge a corresponding quantity, or even a larger quantity, of water. These sluices might be fitted with falling shutters. The largest flushing sluice should be about 150 feet to 300 feet from the head sluice, for it is about this point that the heavy sand is deposited, and where the greatest scour would be required. This system is the most effective and the least expensive for large schemes. If the head sluice on the river bank be constructed on the principle of taking water from the surface of the river, instead of from below, the minimum amount of silt will enter the broad reach, and that can, under favourable conditions, be cleared away, by closing the sluices at the extremity of the broad channel for a short time, and opening all the lower shutters of the head sluice on the river bank and the various flushing sluices.

No. 1,623.—"The Travelling of Sea Beaches."[1] By GEORGE HENRY KINAHAN, M.R.I.A.

Two of the chief points of controversy as regards this subject are: 1st. Whether wind waves or tidal currents are the principal moving agents in the travelling of sea beaches? and 2nd, Whether large stones can be carried by ordinary ocean currents in deep water? During the last twenty years the Author has had opportunities of observing the Irish sea beaches, and especially during the last six years, while stationed in the counties of Wexford and Wicklow. The following is a digest of the results of his observations: Off the south coast of Ireland the flow-wave runs eastward, and off the east coast northward. The flow-tide generates three classes of on-shore currents: 1st, on-shore currents running in a direction generally similar to that of the flow-tide wave; 2nd, counter tides, or on-shore currents, flowing in a contrary direction to that of the flow-tide wave; and 3rd, half counter-tides, or on-shore currents, generated at many of the headlands a few hours before high water. In some places the half counter-tides may run in a contrary direction to the normal currents, and in other places to the counter tides. All these on-shore currents, especially the latter, carry the beaches with them under ordinary circumstances.

The wind waves are of two kinds, viz., ground swells, or waves generated in the Atlantic or Channel, and waves due to the winds blowing directly on the coast. Their effects are either to pile up and fill the beaches, or to cut them out. The ordinary wind waves assist the flow-tide currents when they are going in the same, or nearly the same, direction with those currents. If they strike the beach at a right angle, or nearly so, they pile it up, forming "fulls" and "storm beaches"; while, if they are coming in a more or less opposite direction, they cut out the beach. On the east coast, winds blowing from any points between S. and E.S.E. by E. accelerate the travelling of the beach. From E.S.E. by E. to E.N.E. by E. the beach is piled up; while between E.N.E. by E. and N. the beach is cut out. The cutting out is due to the dancing waves generated by the meeting of the tidal current and the wind waves. These toss and churn up the sand and other

[1] Abstract by the Author of an Original Communication, illustrated by charts and diagrams.

detritus, causing it to be carried out by the backwash into deep water. Continuous heavy winds in the same direction as the flow-tide currents will accelerate the carriage of a beach to such a degree that every particle of it may be carried with the tide; thus leaving the up-stream portion of a beach empty, while a "full" is formed at the down-stream end. Ground swells act differently from ordinary wind waves, as they break on the coast line perpendicularly, or nearly so, with an undulating or rolling motion, which generates a considerable suck or backwash, that cuts out the beaches.

The following is a summary of the general effects of the winds on the beaches of the east coast, between Carnsore and Dalkey:

W. and S.W. winds generate ground-swells, which usually cut out the beaches. In places they drift the sand from the land out to sea or on to the beaches.

S. winds in places cause "fulls" at the northern ends of the strands, due partly to the rapid carriage northward of the beach, and partly to the land driftage of the sand, &c. They often generate ground swells.

S.E. winds carry away the southern ends of the beaches to fill them in at the northern end. At Poulduff (Cahore), it is said two strong twelve-hour gales are sufficient, to cut out and carry north the "fulls" south and north of the pier.

E.S.E. by E. to E.N.E. by E. winds generally heap up the beaches. In places, however, on account of being oblique to the direction of the flow-tide current, they in part cut out, forming transverse ridges on the beach. The flow-tide waves drive up detritus to strand it, while the wind waves suck it out. To form this class of beach the wind waves are not so effective as the tidal current, and the detritus is more stranded than removed; so that while the wind lasts the strand fills.

N.E. winds cut out the northern portions of the beaches, while they sometimes "full" the beaches to the southward. The most remarkable "fulls" due to these winds were in the small bay to the south-west of Kilmichael Point, and the "storm beaches" in the Wicklow and Bray strands. In the first locality, after continuous winds from the north-eastward during the spring of 1876, a foreshore was formed over 200 yards wide, at the base of a cliff, where during the previous winter there was deep water.

With N. winds, no direct influence was observed, except that they seemed to retard the flow of the tide up the Irish Sea.

These results are connected solely with the normal currents flowing in a nearly similar direction to the flow-tide wave. With

the counter tides and half counter-tides the results are necessarily different, in accordance with the directions in which they may be running. Wind waves combined with half counter-tides, always give maximum results, on account of the tide being nearly full, and also because the waves are larger and have greater power.

Ground swells with flow-tides usually cut out. They sometimes form transverse ridges, or beaches similar to those due to easterly winds, but in these cases the cutting out is generally in excess. Ground swells at the beginning of the ebb tide sometimes cut out, especially near Courtown, where the rise and fall of the tide is only a few feet. Ground swells with E. winds sometimes seem to assist in filling in the beaches, but with N.E. winds they cut out. Ground swells with the counter tides cut out the beaches. Ground swells with the half counter-tides, that run east, fill in the beaches.

The cutting out due to ground swell or contrary winds is quite distinct from that due to a S. E. or any favourable wind, as the latter carries the beach along the strand from one place to another, while the former suck out the beach into deep water. Ground swells due to S. winds usually brèak on the shore nearly as quickly as the ordinary waves; but the ground swells due to S. W. and W. winds have intervals of one, two, five, or more minutes between them, and are much larger than the ordinary wind waves, or the tidal waves, which may be breaking at the same time rise much higher on the beach and often at one sweep carry away a mass of materials that it has taken a number of small waves to pile up.

Beaches may be clean swept and left empty: (1) By the tidal current alone, if for a long time there are not any contrary storm waves to stop the travelling of the beach; (2) If there are continuous winds that accelerate the travelling of a beach; or (3) If there are continuous winds that cut out the beach. In any of these cases, if the strand is left empty and a storm comes on, the marginal cliffs are left unprotected and may be rapidly denuded, a small storm having greater power when the beaches are empty than a great storm if the beaches are full, and winds which are most destructive to the beaches may have little or no effect on the marginal cliffs. The best section of a beach to preserve a marginal cliff, is one having below a slope, next above a flat or cess, higher up a second slope, and above all a second flat. Such a section is not common; full beaches more often having a slope below, and a wide flat above. The largest denudation of the coast line is north and south of Kilmichael Point.

Carriage of Stones in deep Water.

If a point a few miles from the shore in from 15 to 20 fathoms of water be chosen, and fixed by bearings, and examined regularly at low water during calms, it will be found that the stones at the bottom of the sea are always changing their position; some being carried away, while new ones are drifted on to the observed ground. On the coast of Galway, in many of the small strands, large blocks, some weighing 2 or 3 cwt., will be stranded after storms, which blocks must have travelled through water 15 or more fathoms deep. At the west end of Tacumshin Æolina sand ridge, there is below the sloping shingle beach a nearly flat sandy strand, usually free from blocks, which, on April 4, 1876, during low water, after a heavy gale from the south-west, was covered with blocks, having deep seaweed attached, while on the slope there were other similar blocks. As the tide rose, these blocks began to drift landward, and in twenty-four hours nearly all the blocks were collected in horizontal lines. Numerous observations also proved, that blocks can be drifted in a considerable depth of water; not by the simple impulse of the currents or storm waves, but by such action combined with the buoyancy given to the stones by the growth of seaweed attached to them; and in the case of small stones, it can easily be seen, during any gale, that the floatage of attached seaweed is often greater than the weight of the stones. With large stones, therefore, it would only be necessary that the stone—no matter what its size, if sufficient seaweed be attached to make it buoyant—should be loosened out of its bed of sand, to allow it to be carried and suspended in any current into which it might be drifted. In deep water the buoyant stones would be gradually and slowly drifted by the tidal currents; but after they come under the influence of the action of the storm waves their carriage would be more rapid.

No. 1,633.—"Description of a new Balance Bridge over the Royal Canal at Dublin." By BINDON BLOOD STONEY, M.A., M. Inst. C.E.

THIS bridge (Plate 6) carries a short branch of the Midland Great Western railway of Ireland across the Royal Canal immediately below Newcomen bridge at the very oblique angle of 25°, and, though the canal is only 15 feet wide, the bridge carrying the railway is 40 feet long on the skew. The trains run over the bridge at from 2 to 3 feet above the ordinary water level, and whenever a boat is passing along the canal, the bridge is lifted from 8 to 13 feet, according to the height of the deck load, so as to permit the boat to pass. The bridge is formed of two strong single plate girders of the usual type which lie underneath the rails, with cross girders and side brackets over which the platform is laid. It is lifted by a lever 40 feet long, formed of two plate girders braced together horizontally and attached at right angles to the centre of the bridge. This lever is balanced at its centre on blunt steel knife edges like the beam of a pair of scales. The weight of the bridge at one end of the lever is counterpoised by an equal weight of metal attached to the other end, so that the whole structure turns freely on the knife edges, which rest on steel pillar blocks dovetailed into the top of metal standards, one on each side of the lever. The opening and closing movements are regulated by a small crab-winch and chain, the ends of the chain being attached to the lever at some distance apart, one on each side of the line joining the knife edges. The centre of this chain is wound on and off the barrel of the winch, which is itself bolted down to a mass of concrete extending beneath the metal standards. The man in charge works this arrangement with ease, and it is so regulated that the bridge can be opened or closed in a little less than one minute. It might be moved faster than this, as the friction is reduced to a mere trifle by the knife edges, but it is not convenient to put a large mass in rapid motion when there is nothing to be gained by so doing.

The weights of the principal parts of the structure are:—

	Tons.	Cwts.
Bridge, including girders, platform and rails . . .	11	15
Lever	8	17
Counterpoise	11	5
Total weight put in motion	31	17
Cast-iron standards	2	13

The total cost of the bridge, including concrete foundations, and a little masonry for repairing the side walls of the canal, was £877 16*s*.

The bridge was erected in 1878, under the Author's direction, in place of a former bridge of a different design which was removed. It was essential that the new bridge should be erected speedily, so as to interrupt the traffic as little as possible, and the first engine passed over it in about twelve weeks after the contractors, Messrs. Courtney, Stephens and Bailey, of Dublin, got instructions to proceed with the work and the traffic was only interrupted for about one week during erection. The lever sloping upwards has a somewhat singular appearance when the bridge is in position for trains to pass over; on the other hand, the bridge has a singular effect when lifted into the air for canal boats to pass beneath, but the Author believes that the strength of the structure, the ease of working and keeping it in order, and its moderate cost, more than compensate for any strangeness in appearance.

The communication is accompanied by a drawing, from which Plate 6 has been engraved.

o. 1,570.—"On the Street and Footwalk Pavements of Montreal, Canada, from the year 1842 to 1878." By PERCIVAL WALTER ST. GEORGE, Assoc. M. Inst. C.E.

HE following tabulated statements, showing the date and mode of nstruction, the first cost of material and labour, the interest and aintenance per annum, of certain roads in Montreal, for a period thirty-seven years, have been compiled from the actual expen-ture on the streets specified, and not from estimates. The tables us form a standard upon which the different systems of pave-ents may be compared. The Author is not aware that any milar tables have ever been published; but if the same informa-on could be obtained from other cities over an equally long riod, it would enable useful and valuable comparisons to be stituted. The mode adopted appears to the Author to be prefer-le to the usual method of comparison by wear in inches.

In arranging the tables, the streets taken as examples are those which the traffic is, in the opinion of the Author, about equally avy in the aggregate. Although this at first may appear to be difficult matter to determine, yet on further consideration it will found that the amount of traction is equally a matter to be cided by the judgment of the engineer. In the 'Annales des nts et Chaussées,' 1877, p. 226, in a Paper on "The Wear of acadamised Roads," by M. Tarbé de Saint-Hardouin, it is stated[1]: For the highways of France the average quantity of material nsumed, in 1875, amounted to 39 cubic yards per mile for one ndred horses; the total number of horses having been two ndred and forty, according to Mr. Lucas. To compare the fore-ing results, the Author takes the weight of the traffic as 2,090 lbs. 50 kilogrammes) per horse for the highways, and 1,320 lbs. (600 logrammes) for Paris. He further assumes the respective dura-lities of the materials to be as 3 to 4."

The above proves, even assuming a comparison by unit traction be the correct method, that a certain weight per horse must be ken, as it is practically impossible to obtain the correct weight, less each individual vehicle passing over a road is weighed, and it must be taken very often, as the traffic is seldom at any time ual during the year. In Canada, for instance, the traffic during

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlix., p. 304.

the winter is practically nil as to wear, the snow lying to a depth of 2 feet or more for at least three or four months continuously; but then the injury done by the frost would compensate in some measure for the lack of traffic. Again, as no record has been kept of the past traffic, it would necessarily be erroneous to take the present traffic for a certain time as a basis, especially when traffic in all cities depends on fluctuations of business.

A comparison of the durability of pavements by unit wear on unit width would likewise be a matter of opinion. If, for the sake of argument, a periodical record of the section of the roadbed be taken, then it will be found, that the wear and settlement of the roadbed are seldom uniform, but confined to certain lines of traffic; whereas the result is based on the whole sectional area of the roadbed. To ascertain the wear by actual measurement of the paving block would be also difficult, as the original block would in all probability vary $\frac{1}{4}$ inch more or less in depth, a circumstance of little importance in itself, but one which would render a comparison of wear impracticable.

As the engineer must use a certain amount of discrimination in classifying streets as to traffic, it is apparent that he would also have to do so by the method of comparison by wear on unit width, and by unit traction; at the same time he would have to class the streets, formed on a level and on an incline, it being evident that there must be less wear on a level road than on a road having an inclination, say, of 1 in 10.

Three examples may be taken, as a proof of the slight difference in the cost of maintenance of streets of somewhat different traffic (see Table I. in the Appendix):

St. James Street	14·845	cents.	per	square yard.
Notre Dame „	14·800	„	„	„ „
St. Paul „	14·910	„	„	„ „

The two former are crowded thoroughfares, in which the traffic is composed of light vehicles; in the latter, the traffic consists of heavy drays. By taking the average cost of maintenance, &c., for a large number of years, of the streets of heavy traffic in large towns, where so slight a difference is shown, a good idea may be obtained of the respective merits of the different systems of pavements. The advantage of certain pavements, as to noiselessness and freedom from dust, has not been considered, as that is a question for the ratepayer and sanitarian, and not for the engineer, who should confine himself solely to the safety, durability, and cost of pavements.

The attention of the Author has been drawn to a Paper read before the Civil Engineers' Club of the North-West, No. 73, on "The Wooden Pavements of Chicago,"[1] by Mr. E. A. Fox. After the reading of the Paper, Mr. S. S. Greeley remarked: "Large as the public interest is, no intelligent thought or scientific examination seems ever to have been given to it by our municipal authorities. The 'vital statistics,' so to speak, of our streets should have been carefully preserved; that is to say a record should have been kept of the date of construction, the description of the persons engaged as contractors or superintendents, and quality of materials used, and of the condition of the pavement at intervals, as to wear, decay, cost of repairing, and the date of its final taking up. Such statistics touching even a few important streets, would give us now a body of facts of very great value as a guide for future construction."

This want was apparent to the Author, and induced him to compile the accompanying tables.

Table I. is a record of street paving, showing the date of construction, the number of years laid, the description of material, with the first cost, interest, and maintenance per superficial yard per annum.

Table II. shows the annual expenditure on the different pavements.

Table III. gives a comparative cost for various periods, and the relative life required to capitalise outlay.

Square Pine or Tamarac Wood Block Pavement was adopted in the year 1842. The blocks varied in size from 6 inches to 11 inches square, and 9 inches high; they rested at an angle of 72°, on a bed of gravel and sand 9 inches deep, the blocks being laid in their natural state. The cost of the material was 4*s.* 3*d.* sterling per superficial yard. The cost of laying is unknown. The average yearly maintenance was about ½*d.* per superficial yard. In the year 1849, after six years, it was almost entirely renewed. In 1852, and until replaced in 1854, the paving was in a very bad condition, the blocks being much decayed underneath. This method was tried in three streets, extending over an area of 35,250 superficial yards, for a period of twelve years.

Limestone Blocks.—Grey limestone blocks, from Montreal, were laid in the year 1854, in the same streets, the dimensions varying from 8 to 18 inches long, 4 inches wide, and 9 inches high. The foundation was of broken stone 9 inches deep, over which there

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lvii., p. 332.

was a coating of 3 inches of river sand, and the blocks were blinded with the same material. The average cost was 8*s.*, and the yearly maintenance ½*d.* per superficial yard. Notwithstanding that the work was badly done, in the opinion of the engineer, the pavement in St. James Street remained in good condition for eleven years, the blocks wearing smooth and becoming slippery. This is no doubt due to the heavy traffic, as Table I. shows that in St. Paul Street, where the traffic is slightly less, the pavement has been laid for twenty-two years. The blocks are now worn smooth but not unevenly. Again, similar pavement has been laid in Custom House Square for nineteen years, and is now in good order. The traffic being less than the above examples, it is not included in the tables of comparison.

In the year 1865, limestone blocks from Brockville, Ontario, were laid in St. Sulpice Street; the blocks were 8 inches long, 3 to 4 inches wide, and 7 inches high; they rested on a layer of 9 inches of concrete, and were grouted in lime. The cost was 10*s.* 6*d.*, and the yearly maintenance ¼*d.* per superficial yard, the area being 1,254 superficial yards. After thirteen years' wear, the paving is in good order, the blocks being slightly worn.

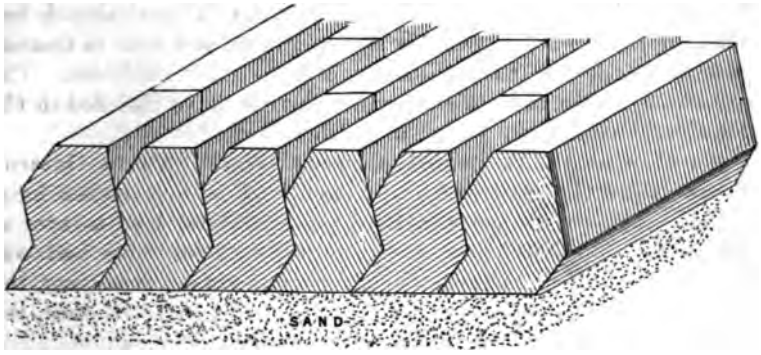
Granite Blocks from the Furness quarries, Glasgow, Scotland, of the same dimensions, were imported and laid in a similar manner in 1865, adjoining the last-mentioned paving in St. Sulpice Street, at a cost of 14*s.* 4½*d.* per superficial yard, over an area of 459 superficial yards. After thirteen years the roadway is in good order, and the blocks show little wear. This may be considered the best piece of paving in the city.

Since the year 1875, granite and syenite blocks, from Gananoque and Montreal, 12 inches long, 3 inches wide, and 6 inches high, have been laid in the same manner, and up to the present time the blocks have given satisfaction. The cost has been in excess of the Scotch granite, varying from 18*s.* 2*d.* to £1 0*s.* 2½*d.* per superficial yard; but with the decrease in the cost of carriage and of labour, it can now be laid for at least one-third less. The late Sir William Logan stated that this stone compared favourably with the best granite of Great Britain.

Nicholson Wood Pavement was laid in 1865 in Jacques Cartier Square. It is formed of pine blocks, 6 inches long, 3 inches wide, and 6 inches high, resting on a double flooring of 1-inch boards. The usual method of laying such a pavement was adhered to. After six years it was necessary to renew a great portion of it, the blocks being much decayed, although the plank flooring was in good order. Two years afterwards it was nearly impassable. The

first cost was 6*s.* 11¼*d.*, and the cost of relaying, after six years' wear, is taken at about 5*s.* per superficial yard, as per average tenders, and as shown in Table III. The area laid was 4,360 superficial yards.

BALLARD WOOD PAVEMENT was laid in 1872 in St. James Street, over an area of 7,527 superficial yards. It is formed of wedge-shaped pine blocks, 10 inches long, 4 inches wide, and 6 inches



high, resting on a bed of sand upon gravel. Over the blocks was laid a similar composition to that used in the Nicholson pavement. The first cost was 11*s.* 8½*d.* per superficial yard. After five years it was much worn, and had to be taken up. The cost of relaying is estimated at 10*s.* 6*d.* per superficial yard, and the life (Tables II. and III.) is estimated at six years, being similar to the Nicholson, and giving it all the advantage possible. The maintenance was calculated from the cost of relaying, over a period of six years, the same as the Nicholson. By that means the comparative cost, for various periods, for the different systems can be seen. The advantages claimed for the Ballard pavement in comparison with the Nicholson pavement are: 1st, absence of flooring boards; 2nd, the locking of the blocks to give greater homogeneity; and 3rd, as no nails are used, a row of blocks can be slipped out, by taking out the first row at the watercourse, thus affording facilities for laying gas and water pipes, &c.

MACADAM PAVEMENT, formed of 2-inch broken syenite, varying from 12 to 18 inches deep, and rolled with an Aveling and Porter 15-ton steam roller, has been laid in different streets. (Table I.) For streets of heavy traffic, notwithstanding that the first cost is somewhat less than most pavements, the maintenance is greater, the average being from 5*d.* to 7*d.* per superficial yard yearly.

This pavement has always been in bad order, requiring constant repairs and cleaning.

A review of the different methods of street paving (Table III.) shows that, for heavy traffic, granite blocks, either from Scotland or from Canada, the former being the cheaper, form the least expensive and the most durable pavement. The first cost is 14*s.* 4½*d.* per superficial yard, for a period of seven, thirteen, and nineteen years, no maintenance having been required; and it will undoubtedly last for a much longer period. The blocks, after thirteen years, have shown few signs of wear, and with care and judgment in laying, the results are good.

Limestone blocks from Brockville, Ontario, have also been laid for a period of thirteen years; and although the blocks show slight signs of wear, the roadway is in good order. Still the blocks do not retain their grit, and during wet weather horses are liable to fall. This paving costs 3*s.* 10½*d.* per superficial yard less than the granite, and the maintenance for thirteen years has been at the rate of 0·158*d.* per superficial yard per annum, lessening the difference in nineteen years from 3*s.* 10½*d.* to 3*s.* 7½*d.*

Macadam for light traffic is good, and when clean is preferable to stone blocks. But with heavy traffic it is impossible to keep it in order, and after nineteen years it costs 7½*d.* per superficial yard more than the granite. The fact of its being always dirty, and wearing into holes and ruts, places it far below granite blocks.

Nicholson wood pavement, although noiseless and comfortable to travel on, in thirteen years is greater in cost of maintenance than granite blocks by 2*s.* 5½*d.*, and in nineteen years by 7*s.* 3½*d.* per superficial yard.

Ballard wood pavement is in one respect superior to the Nicholson. It can be more easily taken up in laying gas and water pipes, &c., as already described; but the cost is greater than granite blocks in seven years by 5*s.* 6½*d.*, in thirteen years by 13*s.* 9*d.*, and in nineteen years by £1 2*s.* per superficial yard, and proportionately greater than the Nicholson.

Granite and syenite blocks from Canada have so far worn well, but experience of them being limited, and the first cost being greater at the time they were laid, has excluded them from competing with Scotch granite blocks.

The Telford pavement has not had a fair test. The example quoted was laid in a street of heavy traffic, for which it is hardly suitable, although the first cost is less than macadam by 1*s.* 7½*d.*

It is evident that the granite-block pavement is superior to the other enumerated pavements for heavy traffic in the climate of

Canada, and that the cost for a period of nineteen years is 7½*d.* less than macadam, 7*s.* 3½*d.* less than the Nicholson pavement, and £1 2*s.* less than the Ballard pavement, per superficial yard.

Add to the above the cost of cleansing, which is in favour of the stone block pavement, viz.:

Macadam.	St. James Street.	2·20 cents per square yard	mean 2·23 cents per square yard.
„	Notre Dame . .	2·27 „ „ „ „	
Stone block.	McGill . . .	0·90 „ „ „ „	mean 1·37 cents per square yard.
„	St. Paul . . .	1·84 „ „ „ „	

This difference in favour of stone blocks is borne out by a statement furnished by M. Vauthier in 'Annales Industrielles'[1] for October 21 and November 4, 1877, to which is added the proportional cost in Montreal:

	Cleansing Paris. Per sq. yd.	Cleansing Montreal. Per sq. yd.
	d.	*d.*
Stone pavement	3·37	0·71
Macadam	7·31	1·16

The difference in the cost of cleansing the streets in the two cities may be accounted for in this way, that the rainfall is less in Montreal, the atmosphere clearer, and that the streets are only cleansed during twenty-five weeks of the year, the remainder of the time being during the winter season.

Rainfall in	Montreal,[2] 1877	15·02 inches.
„	Paris, „	22·64 „
„	London „	24·40 „

The following remarks may help to prove the preference shown for granite pavements.

Mr. Allan Campbell, Commissioner of Works, New York, reports, September 30th, 1877: "Five contracts of 67,026 square yards of stone-block pavement have been completed. I have received many urgent appeals for repaving various streets, both up and down town, in the coming year. Some of the wooden pavements, which have now been down six or eight years, are utterly decayed, and must either be replaced with stone next year, or the rotten wood should be removed, and the traffic carried on upon the bare earth," &c.

A Board of Health Committee of Washington reported the following: "That probably four-fifths of the newly-paved streets of our city are paved with wood, varying in kind, some having

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lii., p. 375.

[2] Snow, 48·55 inches = rain 7·03 inches, not included.

been treated with antiseptics before being laid. That within three years from the time they were laid every one of them gave more or less evidence of very rapid decomposition, and some of them have decayed so rapidly as to give rise to a mass of dangerous putrefaction. That, moreover, the broken surface of the pavements above-mentioned has allowed the lodgment of an immense quantity of animal and vegetable filth, impossible even to calculate, between and under the blocks of wood, not only greatly increasing the putrefying mass, but adding to the rapidity of its decomposition. That from said decomposition gases arise, fungi and infusoria develop, which, entering the air we breathe, are poisonous, engendering zymotic diseases, such as typhoid, malarial and intermittent fever, dysentery, diphtheria, &c. And the Committee pray that so soon as the wood pavements give evidence of general decomposition they be removed. This report is endorsed by the City Engineer, who says further, that the only way to repair them is to get rid of them."

Footwalk Pavements.

The footwalks outside the business portion of Montreal have commonly been made of 3-inch planks of pine and hemlock, laid on tamarac sills, which are now gradually being replaced, on account of their unhealthiness, New York blue stone or mountain graywacke having been laid during the last two years.

Sandstone Flags.—Red sandstone, from Caithness, Scotland, was imported about the year 1860, as an improvement on the Staffordshire bricks, at that time generally used in the business portion of the city. The bricks wore well, but their appearance was not liked, and they afforded less facility for the laying of drain connections, &c. The red sandstone has been laid for sixteen years, at a first cost of 10*s.* 11*d.*, and a yearly maintenance of 0·089*d.* per superficial yard, on a foundation of about 8 inches of river sand, and grouted in cement. From eighteen examples, over an area of 1,868 superficial yards, seventeen are in fair order, one required relaying, and two during that period have been relaid. The flags are in good order, although in relaying them the edges were found to be brittle, causing them to scale. They are 2 feet to 3 feet square, and from 2 to 3 inches thick, which is too small for appearances.

Potsdam red sandstone, from Potsdam and Malone, New York State, was imported some years afterwards, and laid at a first cost of 8*s.* 2½*d.*, and a yearly maintenance of 0·094*d.* per superficial yard, in a similar manner to the above, and of about the same size.

From twenty-eight examples, over an area of 1,870 superficial yards, during thirteen and a half years, twenty-seven are in fair order, one needs relaying, and five have been repaired. The flags have worn about the same as the Scotch sandstone; yet other flagstones of the same size, which have been used later, appear to retain their surface better.

Grey sandstone, from Cleveland, Ohio, has been laid for three years, at a cost of 11*s.* 3½*d.* per superficial yard. The flags are from 4 to 6 feet square, and from 2½ to 3 inches thick. They have shown no signs of wear, retaining their natural surface, and, being sawn, are more easily laid.

Yellow sandstone, from Chicago, Illinois, has also been used for five years, and has worn well. The flags imported were 11 feet long, 4 feet wide, and 8 inches thick; lying the full width of the walk, and their edges forming the kerbstone. The size of the flags necessitated a concrete foundation 12 inches thick, with a layer of river sand over it. It will undoubtedly remain perfect for many years, but the expense will preclude it from being generally used. The cost per superficial yard was £1 15*s.* 7*d.*

Grey Limestone Flags, from Montreal, have been used for eleven years at a first cost of 15*s.* 6½*d.* per superficial yard, laid in a similar manner. From eleven samples taken over an area of 1,627 superficial yards, none of them have required relaying. The flags have worn smooth, and during the spring and autumn are very slippery. The difficulty in quarrying the size suitable for flags makes them expensive; they have to be cut from blocks, and reduced, by dressing, to even thicknesses, ranging from 5 inches and upwards. They are therefore unable to compete with other flagstones.

Slate Flags have been imported from Rockland, Vermont, and laid at a first cost of 9*s.* 5½*d.* per superficial yard. They have been laid for a very short time, and the quantity has been only 64 superficial yards, but they have given satisfaction. Their average size is from 2 to 3 feet square, and 2 inches thick.

New York Blue Stone, or Mountain Graywacke, has been extensively used for the last three years. To all appearance its tenacity is superior to sandstone, but the flags being found in layers, it is not so easily laid. The cost for 3-feet flags is 10*s.* 9½*d.* per superficial yard; and the average price of flags from 4 to 6 feet square, is 14*s.* per superficial yard. The former price has been quoted in order to compare with the ordinary-sized flags.

Cement.—Walks made of Portland cement have been used for the last eleven years, and have proved a failure. The cement was

laid about 2 inches thick, over a concrete foundation formed of refuse bricks, &c. Any settlement or expansion causes it to become uneven, and crack; at the same time it is very slippery. Its duration has been five years, and subsequent repairs have merely been patchwork. An improvement on the above has been adopted, and has succeeded admirably. Its appearance is equal, or perhaps superior, to that of the large flags. It was thus laid:—First, a layer of 2 feet of sawdust, well rammed and rolled; then 6 inches of concrete; and over all a coating of cement 2½ inches thick, which was divided into sections of about 4 feet wide, with ½-inch joints. It has been laid for four years, and has now commenced to crack laterally, which, in the opinion of the Author, would be entirely avoided if the sections were divided laterally, say into blocks 4 feet square, instead of 11 feet by 4 feet as at present. The cost was 12*s.* 4*d.* per superficial yard.

Coal Tar Composition has been used for the last nine years, at an original cost of 4*s.* 5½*d.*, and an average yearly maintenance of 3·043*d.* per superficial yard. From thirty-five examples, over an area of 5,793 superficial yards, sixteen are in good order, six in fair order, and thirteen are bad; their average life is five years. On the mixing of this composition everything depends. The coal ashes must be clean and well sifted, the sand and ashes dry, and the coal tar of the proper density. The time of laying must be well chosen, guarding especially against changeable weather, as rain falling upon the composition before it is set injures it; and the sun after a summer shower dries it too fast, drawing the tar to the surface, and leaving the coal ashes dry and unbound, which in a short time will appear by blistering and crumbling away. It must be well rolled and sanded, especially where the traffic is not sufficient to make it hard. The composition is formed thus: On a dry foundation is placed a coat of rough clinkers of anthracite coal or iron clinkers from the foundry, mixed with sand and tar in the proportions of 15 cubic feet of fine sifted ashes, 14½ cubic feet of pit sand, 1½ cubic foot of tar = 9 gallons. This is laid about 3 to 4 inches thick, and then well rolled. Over this is placed a coating from 1 to 1½ inch thick, composed of 15 cubic feet of coarse sifted ashes, 15 cubic feet of clinkers, and 1½ cubic foot of tar = 8 gallons. The materials must be thoroughly mixed. Although the generality of such walks have not been satisfactory, three of the examples have been laid nine years, and one eight years, without repairs. The unfavourable result is due to the want of care in preparing the composition, and to the sudden changes in the weather whilst laying, which is unavoidable.

First on the list, Table VI., is the Potsdam sandstone, at a first cost of 8*s.* 2½*d.*, and in nineteen years a cost of 8*s.* 4*d.*, showing the yearly maintenance to be small.

Second, the coal-tar composition; first cost, 4*s.* 5½*d.*, in six years 5*s.* 8*d.*, in thirteen years 6*s.* 11½*d.*, and in nineteen years 9*s.*, per superficial yard; being 8*d.* per superficial yard in excess of the Potsdam.

Third, the Scotch sandstone; first cost 10*s.* 11*d.*, and in nineteen years 11*s.* 0½*d.*, per superficial yard; being 2*s.* 8½*d.* in excess of the Potsdam, and 2*s.* 0½*d.* in excess of the coal-tar composition.

Fourth, the grey limestone from Montreal; first cost 15*s.* 6½*d.*, and in nineteen years the same. This material does not compare favourably with the others, on account of its wearing smooth and becoming very slippery, and also its great expense.

Fifth, the cement walk, which has been left out of the category, as the experience of its duration is limited; but with the improvements suggested in laying, it would rank in regard to cost fourth on the list, and for appearances first.

Sixth, the New York blue stone, or mountain graywacke, from the experience of many cities in the United States, and with the limited experience of Montreal, will be equal to, if it does not surpass, any of the other flagstones in regard to tenacity.

Seventh, the Cleveland sandstone and the New Rockland slate are good materials, and from the experience of other cities in the United States they do not become slippery, and are easily laid; but the experience of those at Montreal being limited, they are not included in the tables of comparison.

In conclusion, the Potsdam sandstone, in regard to cost, maintenance, and durability, ranks first. Time only will show what other materials excel it for cheapness, &c.

APPENDIX.—TABLE I. DIFFERENT SYSTEMS of Str

Date of Construction.	No. of Years Laid.	Streets.	Description of Roadway.	
			Material.	Size.
				Ins. Ins.
1842	12	Great St. James and Place D'Armes .	Square pine and tamarac blocks	9 x 9
1854	18	"	Limestone blocks	13 x 4
1872	5	"	Ballard pine blocks	10 x 4
1877	1	"	Macadam (syenite)	8 deep.
1842	12	Notre Dame .	Square pine and tamarac blocks	9 x 9
1854 to 1858	9[1]	"	Limestone blocks	13 x 4
1876	2	"	Granite in centre of tramway .	12 x 3
			Macadam, each side of tramway	6 deep.
1842	12	St. Paul . .	Square pine and tamarac blocks	9 x 9
1854 and 1858	22	"	Limestone blocks	13 x 4
1867	8	Jacques Cartier Square . .	Nicholson wood pine . . .	6 x 3
1875	3	"	Macadam (syenite)	18 deep.
..	9[2]	Wellington .	Macadam (syenite)	12 deep over.
..	8[3]	Foundling. .	Macadam (syenite)	18 deep over.
1877	1	"	Syenite stone blocks. . . .	10 x 3
1865	13	St. Sulpice .	Scotch granite blocks . . .	8 x 3½
1865	13	"	Brockville limestone blocks .	8 x 3½
..	18[4]	St. Ann's Market, north side . . .	Cobble stone pitching . . .	..
1877	1	"	Syenite stone blocks	10 x 3
1875	3	McGill . .	Granite (Gananoque) . . .	12 x 3
			and syenite stone blocks . .	10 x 3
1875	3	St. Joseph. .	Syenite stone blocks. . . .	10 x 3
1877	1	Commissioners	Telford (syenite).	Top coat
1858	19	Custom House Square . .	Lime stone block	13 x 4

[1] Street widened in 1865; blocks worn smooth. [2] Average of maintenance for nine years. On

in the CITY of MONTREAL, from 1842 to 1878.

st of Material and Labour.			Interest at 7 per cent., and Maintenance per Sq. Yard per Annum.			Remarks.
Rate.	Amount.		Interest.	Maintenance.	Total.	
$	$	Cents.	Cents.	Cents.	Cents.	
..	..	..	..	0·323	..	After six years in bad order.
2·00	16,180	00	14·006	0·845	14·845	After eleven years blocks worn smooth.
2·85	21,451	95	19·950	..	19·950	When taken up in bad order.
0·56	2,445	77	3·920	..	3·920	
..	..	..	..	1·060	..	After six years in bad order.
1·89½	25,636	00	13·260	1·540	14·800	
4·75	7,014	32	33·290	..	33·250	
0·52	4,281	18	3·640	..	3·640	
..	..	..	..	0·630	..	After six years in bad order.
1·93	26,398	00	13·510	1·400	14·910	Fair order, blocks worn smooth
1·68½	7,350	30	11·795	..	11·795	After six years in bad order.
1·83	7,982	38	12·810	..	12·810	Very good order.
1·83	38,430	00	12·810	9·840	22·655	
1·83	5,916	39	12·810	10·120	22·930	
4·44	6,060	60	31·080	..	31·080	
3·50	839	65	22·500	..	22·500	Very good order.
2·55	3,199	87	17·850	0·321	18·171	Good order, blocks slightly worn.
..	..	..	..	3·700	..	1866, relaid very rough.
4·44	6,358	08	31·080	..	31·080	
4·92	38,711	16	34·440	..	34·440	
4·61	20,555	99	32·270	..	32·270	
1·44½	4,795	71	10·110	..	10·110	
1·76½	2,146	50	12·350	0·058	12·408	Good order (light traffic).

a. per yard. [3] Average of maintenance for eight years. [4] Average maintenance, eighteen years.

TABLE II.—COMPARATIVE AVERAGE FIRST COST, and MAINTENA

Number of Examples.	Number of Years Laid.	Description of Roadway.		First Materi Labou Squar
		Material.	Size.	
3	17	Limestone blocks (Montreal) . .	Ins. Ins. Ins. 13 × 4 × 9	8
1	13	„ „ (Brockville) .	8 × 3½ × 7	10
1	13	Scotch granite blocks (Glasgow) .	8 × 3½ × 7	14
2	9[1]	Macadam (syenite, Montreal). .	18 deep.	7
1	8	Nicholson wood blocks . . .	6 × 3 × 6	6
1	5	Ballard „ „ . . .	10 × 4 × 6	11
1	2	{Granite blocks (Gananoque, Canada) . . . . . }	12 × 3 × 6	19
2	3	Syenite blocks (Montreal) . . .	10 × 3 × 6	19
1	1	Telford (syenite, Montreal) . .	Top coat 9 deep.	5

TABLE III.—(PERIODICAL EXPENDITURE, LESS INTEREST.) COMPARATIVE

Number of Examples.	Number of Years Laid.	Description of Roadway.		T Ca O ? p S Cos Life
		Material.	Size.	
3	17	Limestone blocks (Montreal) . .	Ins. Ins. Ins. 13 × 4 × 9	1
1	13	„ „ (Brockville). .	8 × 3½ × 7	
1	13	Scotch granite blocks (Glasgow) .	8 × 3½ × 7	1
2	9	Macadam (syenite, Montreal) .	18 deep.	
1	8	Nicholson wood pine blocks . .	6 × 3 × 6	
1	5	Ballard „ „ „ . .	10 × 4 × 6	
1	2	{Granite blocks (Gananoque, Canada) . . . . . }	12 × 3 × 6	1
2	3	Syenite blocks (Montreal) . . .	10 × 3 × 6	1
1	1	Telford (syenite, Montreal) . .	Top coat 9 deep.	

[1] For maintenance, an average for nine years taken; road always in ha

of DIFFERENT SYSTEMS of STREET PAVING.

r cent., and Main-Quare Yard, per inum.		Life in Years.	Remarks.
ain-ance	Total.		
d. ·622	d. 7·321	..	After eleven years; blocks wore smooth.
·158	8·964	..	Pavement in good order; blocks slightly worn.
..	11·100	..	Pavement in very good order; blocks not worn.
·992	11·311	..	
·866[2]	15·684	6	
·444[2]	26·286	6	
..	16·403	..	No signs of wear at date, centre of tramway.
..	15·920	..	Blocks no sign of wear; not well laid.
..	4·987	..	Traffic excessive; results doubtful.

the DIFFERENT SYSTEMS of STREET PAVING for VARIOUS PERIODS.

Cost per Square Yard for a period of						Remarks.
ears.	13 Years.			19 Years.		
d.	£.	s.	d.	£.	s.	d.
2½	0	8	4½	0	8	8½	After eleven years, blocks worn smooth.
7	0	10	8	0	10	9	Pavement in good order; blocks slightly worn.
4½	0	14	4½	0	14	4½	Pavement in very good order; blocks not worn.
0	0	12	6	0	15	0	Traffic excessive; road always in bad order.
10½	0	16	9½	1	1	7½	After six years, relaid.
11	1	8	1½	1	16	4½	„ „ „ „
..	..			..			Blocks not worn; can be laid now at 1s. 3d. less both for material and labour.
..	..			..			
..	..			..			Traffic excessive; results doubtful.

[2] After six years, relaid.

TABLE IV.—DIFFERENT METHODS of LAYING SIDEWALK

Date of Construction.	No. of Years Laid.	Streets.	Material.	
			Description.	Quantity
				Square Yards.
1862	16	St. Paul	Scotch Caithness flagstone (red sandstone) . . .	42
1863	15	"	" "	36
1863	15	"	" "	348
1864	14	"	" "	18
1862	16	Commissioners. . .	" "	239
1863	15	" . . .	" "	110
1864	14	" . . .	" "	16
1862	16	St. Peter	" "	178
1863	15	"	" "	42
1862	16	Hospital	" "	13
1863	15	Victoria Square . .	" "	100
1863	15	St. Sulpice . . .	" "	9
1860	18	Notre Dame . . .	" "	11
1860	18	" "	" "	9
1860	18	" "	" "	5
1860	18	" "	" "	
1860	18	" "	" "	1
1861	17	Beaver Hall Square and Place	" "	1
1875	3	Great St. James . .	Rockland slate	
1873	5	" " . .	Yellow sandstone (Chicago, Illinois)	
1875	3	Craig	Yellow sandstone (Cleveland, Ohio)	
1877	1	Commissioners. . .	" "	
1864	14	St. John	Potsdam red sandstone (New York State) . .	
1864	14	Hospital	" "	
1864	14	St. Alexis	" "	
1864	14	Craig	" "	
1864	14	Chenneville . . .	" "	
1864	14	St. Mary	" "	
1864	14	"	" "	

ITY of MONTREAL, from 1860 to 1878.

Labour. Total First Cost.		Interest at 7 per cent. per Annum.	Maintenance.	Total per Annum per Square Yard.	Remarks.
$	Cents.	Cents.	Cents.	Cents.	
126	00	21·0	None	21·000	Fair order. Flags wear smooth, and scale.
109	11	21·0	„	21 000	Fair order.
696	12	14·0	0·040	14·040	Do. 8·7 square yards relaid in 1866.
54	00	21·0	None	21·000	Fair order.
958	28	28 0	3·24	31·240	Do. Relaid in 1867 and in 1877; 71 square yards replaced.
442	00	28·0			Do.
50	10	21·0	None	21·000	Do.
533	61	21·0	„	21·000	Do.
128	34	21·0	„	21·000	Do.
40	95	21·0	„	21·000	Do.
300	48	21·0	„	21·000	Do.
189	16	14·0	„	14·000	Do.
225	33	14 0	„	14·000	Do.
183	00	14 0	„	14·000	Do. Relaid in 1876, as gradient of street was altered; about 50 per cent. broken and scaly.
72	00	14·0	„	14·000	Do.
139	77	14·0	„	14·000	Do.
275	77	14·0	„	14·000	Do.
262	00	14·0	„	14·000	Requires relaying; flags in fair order.
147	20	16·10	„	16·100	At present in good order; no experience as to durability.
646	00	60·62	„	60·62	Flags 10 feet 6 inches long by 4 feet wide, and 8 inches thick; no kerbstone required.
88	00	19·25	„	19·25	Sawed flags; have not worn.
580	00	20·30	„	20·30	
54	26	14·00	„	14·000	Fair order; flags wear smooth, and scale.
58	00	14 00	„	14·000	Fair order.
86	00	14·00	„	14·000	Do.
177	60	14·00	„	14·000	Do.
108	00	14·00	„	14·000	Do.
198	00	14·00	„	14·000	Do.
44	00	14·00	„	14·000	

TABLE IV.—DIFFERENT METHODS of LAYING SIDEWALK

Date of Construction.	No. of Years Laid.	Streets.	Material.	
			Description.	Quanti
1864	14	St. Mary	(Potsdam red sandstone) (New York State) . .	Squar Yard 47
1864	14	„	„ „	21
1864	14	„	„ „	25
1864	14	Dorchester	„ „	255
1864	14	Beaver Hall Square .	„ „	187
1864	14	St. Helen	„ „	56
1864	14	„	„ „	19
1865	13	„	„ „	60
1864	14	St. Paul	„ „	84
1865	13	„	„ „	54
1865	13	St. Sulpice	„ „	84
1865	13	„	„ „	10
1865	13	„	„ „	3
1865	13	„	„ „	19
1865	13	„	„ „	3
1866	12	„	„ „	1
1866	12	„	„ „	1
1866	12	Commissioners. . .	„ „	
1864	14	Hospital	„ „	
1865	13	Recollet	„ „	
1865	13	Jacques Cartier Square	„ „	
1864	14	St. Lawrence . . .	„ „	
1867	11	Great St. James . .	Limestone, Montreal . .	1
1867	11	„ „ . .	„ „ . .	
1867	11	St. Peter	„ „ . .	
1867	11	„	„ „ . .	
1867	11	Commissioners. . .	„ „ . .	1
1867	11	„ . . .	„ „ . .	1
1867	11	„ . . .	„ „ . .	1
1867	11	„ . . .	„ „ . .	
1867	11	„ . . .	„ „ . .	1
1867	11	Hospital	„ „ . .	
1867	11	St. Paul	„ „ . .	

ITY of MONTREAL, from 1860 to 1878—*continued.*

Labour. Total First Cost.		Interest at 7 per cent. per Annum.	Maintenance.	Total per Annum per Square Yard.	Remarks.
$	Cents.	Cents.	Cents.	Cents.	
94	00	14·00	None	14·000	
43	26	14·00	„	14·000	
50	76	14·00	„	14·000	
510	00	14·00	„	14·000	
394	00	14·00	1·18	15·180	Partly relaid in 1869.
112	50	14·00	0·44	14·044	Do. do.
38	28	14·00	None	14·000	
126	71	14·56	„	14·560	
68	84	14·00	„	14·000	
133	38	14·56	1·93	16·490	Partly relaid.
173	47	14·56	None	14·560	
211	05	15·46	„	14·560	
71	95	14·56	„	14·560	
400	40	14·56	„	14·560	
67	85	14·56	„	14·560	
25	04	14·56	„	14·560	
47	22	14·56	1·38	15·940	Partly relaid in 1871.
95	68				
40	76	14·00	0·46	14·460	Do. do. 1867.
126	88	14·56	None	14·560	
180	17	14·56	„	14·560	Requires relaying.
104	00	14·00	„	14·000	
517	92	27·30	„	27·300	Good order; flags worn smooth.
253	89	27·30	„	27·300	
202	88	22·40	„	22·400	
169	54	22·40	„	22·400	
965	25	27·30	„	27·300	
1,404	39	27·30	„	27·300	
663	39	27·30	„	27·300	
374	12	27·30	„	27·300	
1,315	47	27·30	„	27·300	
204	00	28·00	„	28·000	
219	96	27·30	„	27·300	

TABLE IV.—DIFFERENT METHODS of LAYING SIDEWALKS

Date of Construction.	No. of Years Laid.	Streets.	Material.	
			Description.	Quantity.
				Square Yards.
1867	11	Jacques Cartier Square	Coal-tar composition	131·5
1867	11	" "	" "	312·6
1867	11	Place D'Armes	" "	304·7
1867	11	" "	" "	343·3
1869	9	Great St. James	" "	40·7
1867	11	St. Mary	" "	325·0
1867	11	"	" "	91·7
1867	11	"	" "	60·8
1867	11	"	" "	124·7
1867	11	"	" "	143·5
1867	11	Dalhousie Square	" "	223·4
1867	11	St. Francois Xavier	" "	124·2
1869	9	" "	" "	218·0
1867	11	" "	" "	126·6
1867	11	Craig	" "	549·0
1869	9	"	" "	62·5
1869	9	"	" "	158·5
1869	9	"	" "	161·4
1867	11	Dorchester	" "	50·7
1867	11	St. Constant	" "	198·0
1869	9	Recollet	" "	81·0
1869	9	St. Helen	" "	31·9
1869	9	Sherbrooke	" "	189·7
1869	9	"	" "	318·8
1869	9	Drummond	" "	415·1
1873	5	St. Lawrence	" "	104·9
1873	5	St. Peter	" "	102·9
1873	5	Ontario	" "	168·7
1873	5	"	" "	116·2
1873	5	Craig	" "	73·0
1873	5	"	" "	36·0
1873	5	St. Elizabeth	" "	30 3
1873	5	St. Antoine	" "	20·8
1873	5	"	" "	157·0
1873	5	Sherbrooke	" "	196·1
1867	11	Jacques Cartier Square	Cement (Bacerini)	547 7
1867	11	St. James	" "	325·0
1874	4	" "	Cement (in blocks)	78·1
1874	4	St. Lambert	" "	55·2

City of Montreal, from 1860 to 1878—*concluded.*

Labour. Total First Cost.	Interest at 7 per cent. per Annum.	Maintenance.	Total per Annum per Square Yard.	Number of Years laid before Repairs.	Remarks.
$ Cents.	Cents.	Cents.	Cents.		
164 37	8·75	4·00	12·75	5	
390 75	8·75	4·00	12·75	5	
380 87	8·75	8·00	16·75	5	
429 20	8·75	8·00	16·75	5	
40 70	7·00	5·00	12·00	6	
406 25	8·75	8·00	16·75	5	
114 62	8·75	4·00	12·75	6	
76 00	8·75	8·00	16·75	5	
155 87	8·75	8·00	16·75	5	
179 37	8·75	8·00	16·75	5	
279 25	8·75	8·00	16·75	5	
155 25	8·75	4·00	12·75	8	
218 00	7·00	5·00	12·00	6	
158 25	8·75	4·00	12·75	8	
686 25	8·75	8·00	16·75	5	
37 50	4·20	10·00	14·20	5	
158 50	7·00	5·00	12·00	5	
96 84	4·20	5·00	9·20	5	
63 37	8·75	16·00	24·75	6	
247 50	8·75	16·00	24·75	6	
81 00	7·00	10·00	17·00	5	
31 90	7·00	10·00	17·00	5	
189 70	7·00	None	7·00	9	
318 80	7·00	„	7·00	9	
415 10	7·00	„	7·00	9	
104 90	7·00	10·00	17·00	4	
102 90	7·00	None	7·00	5	
168 70	7·00	10·00	17·00	2	
116 20	7·00	10·00	17·00	2	
73 00	7·00	10·00	17·00	2	
36 00	7·00	10·00	17·00	2	
30 30	7·00	None	7·00	5	
20 80	7·00	„	7·00	5	
157 00	7·00	„	7·00	5	
196 10	7·00	„	7·00	5	
684 62	8·75	3·10	11·85	6	Cracks and becomes uneven; very slippery in winter.
406 38	8·75	3·10	11·85	6	
234 30	21·00	None	21·00	..	Good order, retains its grit.
165 60	21·00		21·00	..	

TABLE V.—COMPARATIVE AVERAGE FIRST COST, and MAINTENANC

Number of Examples.	Number of Years Laid.	Description of Sidewalk.	First Cost, Material an Labour, per Square Yar
			£. s. d
35	9·0	Coal-tar composition	0 4 5
28	13·5	Potsdam sandstone, red (New York State) .	0 8 2
1	3·0	Slate (Rockland)	0 9 5
..	2·0	New York blue stone, or mountain graywacke	0 10 9
18	16·0	Scotch sandstone (Caithness)	0 10 11
1	3·0	Grey sandstone (Cleveland, Ohio). . . .	0 11 3
2	4·0	Cement, Portland, in blocks	0 12 4
11	11·0	Grey limestone (Montreal)	0 15 6
1	5·0	Yellow sandstone (Chicago)	1 15 7

TABLE VI.—(PERIODICAL EXPENDITURE, LESS INTEREST.) COMPARATIVE CO

Number of Examples.	Number of Years Laid.	Description of Sidewalk.	Time to Capitalis Outlay a 7 per cen showing C parative l required f each Meth
			Years.
28	13·5	Potsdam sandstone, red	7·5
35	9·0	Coal-tar composition	4·0
18	16·0	Scotch sandstone, red	10·0
11	11·0	Grey limestone	14·3
2	4·0	Cement, Portland, in blocks	11·3
1	3·0	Slate (Rockland)	8·7
..	2·0	Blue stone, or mountain graywacke . . .	9·9
..	3·0	Grey sandstone	10·4

NNUM, of DIFFERENT SYSTEMS of LAYING SIDEWALKS.

st at 7 per cent. Maintenance per Square Yard per Annum.		Life.	Remarks.
Maintenance.	Total.		
d.	d.	Years.	
3·043	6·772	5	Durability uncertain; depends on the weather in laying.
0·094	7·000	over 14	Flags small; good order.
None	7·942	..	„ „ „ „
„	9·047	over 16	No experience. Flags large; good grit.
0·089	9·275	..	Flags small; good order.
None	9·495	..	Sawn flags; good grit.
„	10·360	..	Blocks 11 feet by 4 feet; retains good grit.
„	13·053	over 11	Wears smooth; slippery in winter.
„	29·906	..	Flags 11 feet by 4 feet, by 8 inches thick; does not need kerb-stone.

AINING the DIFFERENT SYSTEMS of LAYING SIDEWALKS for VARIOUS PERIODS.

parative Cost per Square Yard for a period of			Remarks.
6 Years.	13 Years.	19 Years.	
s. d.	s. d.	s. d.	
8 3	8 3	8 4	Good order.
5 8½	6 11½	9 0	
10 11½	11 0	11 0½	„ „
15 6½	15 6½	15 6½	Flags wear smooth.
12 4	..	..	Very handsome; good grit.
..	..	..	No experience as to durability.
..	..	..	„ „ „ „
..	..	..	„ „ „ „

No. 1,405.—"Description of several Bridges erected in Switzerland; with remarks on Bridges of large Spans, and on the Stability of Arches."[1] By JULES GAUDARD, Civil Engineer, Professor at the Academy of Lausanne. Translated from the French by L. F. VERNON-HARCOURT, M.A., M. Inst. C.E.

THE Author is indebted to M. L. Gonin, of the Canton de Vaud, for the drawings of two bridges; one constructed of ashlar masonry some years ago at a considerable expense, and the other built of Portland cement concrete at a small cost.

The bridge over the River Broye at Lucens (Plate 7) has a span of 78 feet 9 inches, and a rise of 9 feet 10 inches. The abutments, which have a thickness of 36 feet at the base, and have been built with radiating courses, rest upon piles driven about 20 feet into a bed of clay. The ornamental pilasters, the tooth moulded plinths, and the pains taken in the execution of the work, give a suitable finish to a bridge designed with special care. Unfortunately the large estimated cost was increased by the damage and expense caused by frequent irruptions of the river into the foundations, the long duration of the works, the increase in the quantity of ashlar masonry, and a lawsuit with the contractor. The total cost consequently amounted to £11,126.

The Vevey bridge, built in 1874, presents a contrast to the preceding example in the rapidity and economy of its construction (Plate 7). Cement concrete was employed instead of ashlar masonry. Shingle and gravel were obtained from the lake close to the works for the concrete; and the materials of the piers of a foot bridge, which the contractor undertook to remove, were also employed. The slow-setting Portland cement used in the works was made at the Virieu-le-Grand factory. It is of the best quality, and makes excellent concrete. The contractor, M. Delastre, the head of the cement factory, had previously executed several similar works, amongst which may be cited the two-arched bridge of La Plaine, near Geneva, and the bridge built, in 1873, at Rohrbach, on the road from Langenthal to Huttwyl. The

[1] This is only a portion of a Paper bearing the following title, "Notes sur quelques travaux en Suisse, et sur diverses questions de théorie."

Vevey bridge has a span of 63 feet 4 inches on the skew, the angle of skew being 71° 40′, with a rise of only 4 feet 7 inches, and a width of 36 feet 5 inches; and though the faces of the bridge have been moulded to imitate ashlar arch stones, the structure is in reality a monolith. The open-work parapet gives a pleasing appearance, and, moreover, facilitates a rapid drying of the concrete, diminishing the chance of the subsequent formation of cracks from contraction. The mouldings are rounded off to prevent injury from wear and tear, or from knocks. The concrete used for the work contained from 250 to 340 lbs. of cement per cubic yard in the foundations, and 420 lbs. in the superstructure. The total contract sum was £1,620, of which £1,480 represents the cost of the bridge, and £140 that of the inverted apron, which is 18 inches thick, and has a dip of 1 foot 8 inches. The cost per cubic yard amounted to £1 2*s.* 8*d.*, and the contractor undertook to maintain the bridge for a period of ten years. The bridge was tested by taking over it a wagon so loaded with rails that there was a weight of 5 tons on each pair of wheels. It bore this test very satisfactorily, and the test load might have been considerably increased without danger. The work having been executed in three successive layers, allowed of the employment of very light centering. Although the turning of the arch only occupied a few days, the centering was not removed until a month afterwards, when a slight crack made its appearance in the arch. This closed during the heat of summer, to re-appear in the cold weather with its initial width, which did not exceed $\frac{1}{20}$ inch.

A special kind of iron pier, resting in a large cast-iron shoe placed on wooden piles, was originally designed for the Sauge bridge over the Broye, near its junction with the lake of Neuchatel. It has since been adopted in various places; as, for instance, in the Jura drainage works; at Massonger on the Rhone; and at the landing stage at Vevey. Each upright of the piers of the Sauge bridge is a hollow column, composed of two large Zores-shaped castings placed against one another, and grasping between their flanges the gussets to which the braces are riveted. A cast-iron cap is placed on the top of the uprights, and serves as a bed plate for the plate-iron girders carrying the superstructure. The foot, strengthened by four triangular gussets placed crosswise, is fastened by screw bolts to the cast-iron shoe resting on the top of the wooden piles. These piles, four in number and 1 foot in diameter, are encircled by a wrought-iron collar a little below the iron shoe. At Vevey, and at some other places, a fifth pile is placed in the centre, between which and the others four double blocks of wood

are driven, and are kept in place and tightened up by thin iron wedges thrust in between. In case of need, a little mound of rubble work, deposited under water, ensures the lateral stability of the piles. This system affords a cheap pier for road bridges which are not required to bear heavy loads. The narrow iron piers, moreover, impede the current less than stone piers. For that reason a somewhat similar construction has been adopted for the central bridge over the Reuss, at Lucerne (see *post*, page 317).

M. Chappuis has adopted a modified design at Nidau, by driving six piles in two rows, on which uprights are placed, inclined to one another, and joined by a single cap at the top, so that each pier assumes the very stable form of a pyramid.

The most important construction on the railway from Jougne to Éclépens is the Vallorbes viaduct, 391 feet long, with masonry piers and iron girders across the three spans. The details of this viaduct are shown on Plate 7. Owing to the configuration of the ravine which the viaduct crosses, the side spans have lengths of 125 feet and 82 feet respectively, and the central span 184 feet. The spans are so disproportionate, that the calculations of the strains indicated that, with the central span loaded, the shortest span would tend to rise from the abutment. In consequence, the ends of the girders of this opening were fastened down to the abutment by anchor bolts, consisting of flat iron bars, $23\frac{5}{8}$ inches by $\frac{3}{8}$ inch. If girders thus circumstanced are erected in the summer, it is expedient to leave the bolts somewhat slack, provided no perceptible rocking motion is thereby occasioned, rather than by tightening them up, and by their subsequent contraction by cold, to add to the necessary strains on the bolts. Another means of attaining the same object would be to weight the short span by putting on an extra thickness of ballast, or with masonry.

M. Bridel, who arranged the details of the superstructure, aimed at simplifying the workmanship. With this object he did not hesitate to add the successive increase in the lattice bars in the width only, in spite of the exaggerated appearance of increase in strength thus presented. However, this juxta-position of the bars, instead of putting them one over the other, possesses the advantage of increasing the surface of connection in exact proportion to the increase of strain. The bars in compression are stiff, U-shaped in section; and the bars in tension are of flat iron, which, placed inside, do not impede by projecting flanges the contact of the uprights where the cross girders are attached. The lower flange of the girders differs from the upper in being wider, and in presenting a continuous plane surface at the bottom, without

plates added in steps, which would have prevented, or rendered difficult, the rolling of the girders into their places. The additional section, where needed, is obtained by plates inserted between the bottom continuous plate and the angle irons. Instead of dispensing entirely with these additional plates where not required, narrow packing pieces (8½ inches by ⅜ inch) are substituted for filling up the space under the angle irons. The lower flange is consequently somewhat heavier than the upper flange, the section of which is increased in the usual manner.

The terrible catastrophe that might ensue from a train leaving the rails on a high viaduct is naturally often taken into account. The precaution adopted at Vallorbes against such a contingency consists in strengthening the road by small flat iron braces placed under the rails, with holes through which the bolts pass. The rails are thus perfectly secured against displacement by the jolting of the trains. This arrangement is better than round bolts piercing the centre of the rails, as the rails being specially bored, considerable inconvenience is experienced in maintenance. Other precautionary methods have been adopted elsewhere. For instance, Messrs. Gouin, of Paris, in the viaducts of Ormaiztegui and Otzaurte, which they constructed in the north of Spain, have made the side of the main girder serve as a guard rail, which, though a little too far off to prevent a carriage getting off the rails, would keep it from running off the sleepers. If, however, the train went off the rails towards the 6-foot space, the side guide would be useless, and the wheels would go through the roadway. To provide against this, it would be necessary to make the roadway of Zores-shaped iron plates, as M. Nordling did in the case of several viaducts on the Orleans branch line. These precautionary measures inevitably increase the cost of construction, and possibly some further improvements might be made in this matter of detail. The same precautions would appear necessary on the embankments adjoining the viaduct, as a train traverses a certain distance after leaving the rails before it goes over the parapet, and a train getting off the rails in the middle of a viaduct would be less dangerously situated than if it left the rails as it approached the viaduct.

The Riddes and Wohlhusen iron girder bridges for carrying a single line, were constructed by Messrs. Ott and Probst, of Berne, and the latter is shown on Plate 8, taken from the working drawings kindly furnished to the Author by M. Probst. Both these structures are remarkable for their lightness, and one of them for the complications produced by skew and curvature.

The Riddes bridge over the Rhone is on the Italian line. This

railway has very little traffic, but it will become prosperous if the line across the Simplon is ever constructed. The superstructure is of a tubular form. The girders have lattice bars placed rather wide apart. The vertical bars, which are in compression, consist of four strong angle irons, and the sloping bars are formed of either single or double flat iron, according to the variations of the strains. The upright bars at the extremities are made very strong, and rest on the bed plates; the bed plates at one end are placed on rollers fixed on the abutment. The rollers have a diameter of 6 inches, and are 1 foot 8 inches long. The clear span is 164 feet, and the length of the girders is 172½ feet. The strain on the iron, under a test load of 1½ ton to the lineal foot, does not exceed 3·85 tons per square inch. The testing of the bridge, on the 6th of August, 1872, was perfectly satisfactory. The total weight of the ironwork, exclusive of the bed plates and rollers, amounts to 97½ tons, or 0·566 ton per lineal foot. With the bed plates and their accessories, the total weight is 103½ tons.

The Wohlhusen bridge over the Emme, on the railway from Berne to Lucerne, is on an incline of 1 in 55·5, on a curve of 15 chains radius, and on a skew of 48° (Plate 8). The opening between the abutments, measured on the skew, is 147 feet. The triangular lattice girders are 159½ feet long at the bottom; the bars, both in tension and compression, have a double T section. Large gussets strengthen the connections of the most heavily loaded bars with the horizontal portions. The superstructure, like the preceding example, is tubular in form; but in this instance, instead of a distance between the centres of the girders of 14 feet 9 inches, it was necessary to adopt 17 feet 10½ inches, giving 17 feet clear space, in order to provide for the varying distances between the centre of the roadway and the centre of the bridge, owing to the curve. The oak sleepers, which support the rails, rest on two rows of rail bearers, and these, placed 5 feet 3 inches apart, follow the curve of the line, and form continuous girders traversing the cross girders through openings made in their centres. The two rail bearers are placed at the same level, and packing pieces of wood are placed on one of them, below the sleepers, to give the necessary cant for the curve.

From this arrangement there is a certain irregularity in the distribution of the load between the two girders, and along each of them. The fixed load may be considered as equally distributed, giving a weight of 4½ tons at each bottom joint; but the rolling test-load of 1·2 ton per lineal foot sways at one moment to the right and at another to the left of the tubular girder,

so that the total weights borne by each lower joint of the truss vary (Plate 8). The locus of the moments is not exactly parabolic, but nevertheless the calculation of the strains is perfectly simple. Taking, for instance, the girder B on the right hand side of the diagram, and starting from the abutment where the reaction is 60·6 tons, and stopping at the centre, the successive external forces are: 60·6 tons, 13·4 tons, 12·5 tons, 11·9 tons, 11·5 tons, and 11·3 tons. By taking off the successive weights, the shearing strain diminishes abruptly from one joint to the next, to the following values: 60·6 tons, 47·2 tons, 34·7 tons, 22·8 tons, 11·3 tons, and 0. Multiplying these values by the constant ratio of the distance between each bar to the height of the girder, namely $\frac{14 \cdot 11}{19 \cdot 03} = 0 \cdot 7414$, the successive increments of the strains on the upper horizontal flange are: 46 tons, 35 tons, 25·8 tons, 16·9 tons, 8·4 tons, and 0, which suffice for tracing the dotted line in steps on the diagram (Plate 8), giving the locus of the compressive strains on the upper flange. This locus is merely a graphic summation, which might as well be replaced by an arithmetical series, namely: 45 tons, 80 tons, 105·8 tons, 122·7 tons, 131·1 tons.

The maximum strain of 131·1 tons is provided for in the following manner:

	Inches.	Inch.		
Two vertical plates,	$13\frac{3}{4}$	$\frac{3}{8}$	24 square inches strained to 3·9 tons	
„ horizontal „	$17\frac{3}{4}$	$\frac{3}{8}$	= 94 tons.	
Four angle irons,	$4/6 \cdot 7$	$\frac{3}{8}$ = 10·1	„	
which strained to 3·9 tons			= 40	„
Total resistance . . .			134	„

There is, therefore, a slight excess of strength, which allows for the vertical plates not being really strained up to 3·9 tons in all their fibres.

With regard to the different parts of the lower flange, there is no necessity to make a separate calculation, for their strains are merely a series of means between the strains already given, which can be represented graphically on the diagram as indicated by the dotted lines. The same arrangement of plates suffices also for the central portion. For the girder A, which is subject to a heavier load near the centre, the two horizontal plates ($17\frac{3}{4}$ inches by $\frac{3}{8}$ inch) have been replaced by three plates, each $17\frac{3}{4}$ inches by $\frac{11}{32}$ inch. It must be observed that the ordinates of the diagram

represent the actual strains, not the moments, since the height of the girder, 19 feet, has been used as divisor.

The lattice remains to be considered. With the foregoing load it suffices to multiply the shearing strains by the cosecant of the angle made with the horizon, or more simply to get them by the graphic method from the oblique projections, to obtain the strains on the bars. But it must be remarked that the greatest strain for each bar occurs with a special distribution of the load, for the shearing strain increases when the space between the point in question and the nearest abutment is unloaded. This method of calculation, though not difficult, is perhaps rather long when the inequality of the distribution of the loads precludes the employment of an abridged formula. In practice it is sufficient to calculate merely the maximum and minimum, and to assume an equable decrease between them.

The maximum shearing strain at the abutments is the reaction of 60·6 tons previously given; the minimum in the centre is zero as regards the fixed load, and for the rolling load on the half span only it is:

$$\frac{\overset{\text{Tons.}}{8{\cdot}9} + 2 \times \overset{\text{Tons.}}{8{\cdot}1} + 3 \times \overset{\text{Tons.}}{7{\cdot}5} + 4 \times \overset{\text{Tons.}}{7{\cdot}1} + 5 \times \overset{\text{Tons.}}{6{\cdot}9}}{11} = \overset{\text{Tons.}}{10{\cdot}04};$$

where the denominator 11 is the number of intervals into which the span is divided, and the weights, 8·9 tons, 8·1 tons, &c., are the rolling loads applied to each successive portion of the half span.

Consider now a straight line, representing the shearing strains, fixed by the two extreme ordinates 60·6 tons and 10·04 tons, and that at each distance corresponding to the points of connection of the bars an oblique line, parallel to the bars, is drawn from the top of the corresponding ordinate. These oblique lines give the strain in the direction of the bars, namely, about 64 tons for the bars Nos. 1 and 2, 51·1 tons for Nos. 3 and 4, 37·4 tons for Nos. 5 and 6, 24·6 tons for Nos. 7 and 8, and, lastly, 10·8 tons at the central triangle.

The total weight of the bridge amounts to only 74 tons, or 1½ ton per lineal yard of clear span, which is a satisfactory result. Although the inclination of the bars makes rather a larger angle than 45° with the horizon, the disadvantage is not great, as the algebraical function expressing the loss varies slowly in the neighbourhood of the minimum. It is noticeable that it is the simplest form of triangulated framework which has furnished this satisfactory result. It is, however, not pure theory, but the

practical conditions of construction of iron bridges, which explain the advantages of simple arrangements of lattice bars over multiple ones, or over solid web plates of great height.

Uprights are frequently inserted in girders of bridges to facilitate the connections of the cross girders and wind ties. In any case, the plan adopted by Messrs. Gouin, of Paris, at the bridges erected by them over the Oria, in the north of Spain—namely, placing the transverse wind ties in planes inclined at 45°, which enables them to be connected with the lattice bars—is well worthy of imitation.

As an example of an economical iron road bridge of modern construction might be instanced that across the Reuss, in the middle of the town of Lucerne, completed in 1878 by the firm of Bell, Brothers, of Kriens, from the designs of M. Emile Cuénod and the Author, and replacing an ancient wooden structure. The bridge had a central opening of 65 feet, and two side spans, each of about 50 feet, though the girders were not of equal length in the latter case, owing to irregularities of the quay wall. The current being very strong, it was necessary that the piers should oppose but little resistance to its force. They consisted of a line of six hollow piles, each composed of two U irons, 7 inches across the opening, connected by plate iron cheeks, giving a longer diameter of 7·8 inches to the complete pile, and tied together by diagonal bracing. The foundation consisted of concrete, 1 foot 8 inches deep, laid in a trench excavated in the bed of the river, and surrounding 11-inch timber piles, to which were bolted plate-iron shoes to receive the iron piles of the superstructure. The platform was 32·8 feet wide, of which one-half was devoted to the carriageway, and the remainder to two footways equal in width. There were six main girders of three different constructions. The outer ones, under the balustrade, were simple lattices, 4 feet 6 inches deep; those at the junction of the carriage and footways were likewise lattices, but of somewhat stronger construction, and the upper member of these girders was supplemented by a Zores iron, 7 inches deep, which materially added to the strength, at the same time that it formed the raised edge of the footway and also acted as a gutter, being pierced at intervals for the admission of the rain water from the carriageway. The central girders, being only 3·28 feet deep, and supporting the carriageway, were of the ordinary plate construction. The road and footway were supported by Zores irons bolted to the cross girders, the intervals between the latter being, in the case of the footway, bricked over, so as to carry a bed of concrete on which the paving stones were placed. The ironwork for the girders amounted

to 62 (metric) tons, for the Zores irons to 6 tons, and for the columns of the piers to 13 tons. The total cost of the bridge was 71,720 francs (£2,869), or 134 francs per superficial mètre, say 10*s.* per superficial foot.

On Iron Bridges of Large Span.

The two examples of bridges constructed by Messrs. Ott and Probst, of Berne, already described, are trusses with large meshes, designed with care and remarkably light. The Author does not propose to draw a distinction between them and the American systems, for the lattice, both simple and multiple, had its origin in Europe, as far as iron structures are concerned. He considers that whilst some systems of construction in the United States may be well worthy of imitation, they furnish no ground for unreasoning admiration, and that in fact it is in wooden bridges and suspension bridges that the Americans have really furnished standard types. In the employment, on a large scale, of timber trusses, they were guided by the desire to reduce the first cost, necessitated by their vast network of railways. As regards iron structures, they have been behind Europe, whose various designs they have been able to study at leisure, and have therefore been led to avoid imitating certain heavy types, such as the solid web and the close trellis, in very large spans. Practical considerations alone, not theory, render wide-apart lattice bars preferable to close lattice work or solid webs, when the opening is large. The Americans have been led, from local considerations, to use suspension bridges of very large spans for carrying railways. However, it must be borne in mind that they cannot claim priority in this respect, as the late Mr. Telford, Past President Inst. C.E., in 1820–25 spanned the Menai Straits with a bridge 500 feet in length, and which between the points of suspension of the chain exceeds 558 feet. The Frenchman Chaley first accomplished the span of 820 feet, in 1832, at Fribourg, in Switzerland. It must, nevertheless, be acknowledged that America has far outstripped Europe in this respect. The Fribourg bridge does not carry a railway, and oscillates even under the weight of one man; and there is nothing to compare with the Brooklyn bridge, the large central span of which attains a length of 1,600 feet, except the design of Mr. (now Sir Thomas) Bouch, M. Inst. C.E., for crossing the Frith of Forth by a steel bridge of the same span. England has some large estuaries where the engineer is called upon to display all the resources of his art; and the late Mr. R. Stephenson, Past President Inst. C.E., and the late Mr. Brunel, Vice-President Inst. C.E., proved equal to the

task. In France there are no examples of such large spans, but in that country the erection of piers is practicable, and no necessity exists to copy the immense spans at Niagara, and over the large American rivers. It is unquestionable that the suspension principle is alone suitable for bridging over exceptional spans; and it is necessary to give a proper rigidity, as the American engineers have done. This rigidity is the more easy of accomplishment the larger the span, as the fixed load becomes greater in proportion to the rolling load. The superiority of suspension bridges is due to the fact, as M. Malézieux has shown in his report on "Travaux Publics des États-Unis d'Amérique," that the chains which bear the load are in tension, and the strains themselves keep them in their proper position; whilst structures in compression, liable to fail by twisting, would need to be made rigid, involving an increase of section necessarily costly. Also, wires of iron or steel, owing to their great tenacity, possess coefficients of resistance much higher than those of plate-iron. On the Niagara railway bridge Mr. Roebling has allowed for a strain, on iron wire cables, of 10·8 tons on the square inch—nearly treble the safe strain for plate iron. Lastly, in these kind of constructions, various parts can be lightened by the expenditure of labour upon them: the rods are fastened by means of forged eyes with bolts, &c., instead of by rivets which weaken the average section.

The Author would not suggest that the arched system, subject to compressive strains, should be abandoned. With bridges of only 160 feet span, and even up to 260 feet span, it is by no means difficult, either by giving a good form to the section of the arch, or by a judicious arrangement of the spandrils, to reduce to moderate proportions the excessive weights occasionally used. Moreover, in arched structures the land cables, and the necessary anchorages in suspension bridges, are entirely dispensed with, as well as the high piers. The arch itself will be heavier, but this can hardly be regarded as an inconvenience; for whereas in very large spans reduction of weight is important, in small spans an excess of weight is beneficial in reducing the injurious effects of vibrations. The system of girders is intermediate between the suspension system which is in tension, and the arch which is compression. Girders merely require vertical reactions at the points of support, and consequently half the material is in tension and half in compression. European engineers have long recognised and employed the true calculations of strains, and the best rules of economical design, both in the solid and latticed straight girder, and also

in the bowstring girder, of which Mr. Brunel's Saltash bridge is an example; so that whenever the Americans have diverged from these models they have been unsuccessful. It must be understood that the Author refers here to the principle, and not to defective methods of application resorted to in so many bridges carelessly designed. However, before trying to elucidate the question of principle, some indications of practical agreement should be noted.

M. Malézieux appears to detect in the Bollman, Fink, &c. systems a predisposition to multiply the tension rods in order to diminish the struts. If this desire exists it is scarcely attained, as there is always to be found a horizontal flange, and a series of vertical uprights in compression, amounting altogether to nearly half the weight.

The Author, moreover, does not consider that American designers can lay claim to priority in the combination of wood and iron, as this was first done by English engineers in many triangular lattice-girder bridges, such as the Crumlin viaduct, the Great Northern railway bridge over the canal at Newark, and various bridges in India. The reason why iron is preferred to a combination of two heterogeneous materials is, that such a combination is inconvenient when the structure has superabundant pieces which may prevent each bar from bearing that portion of the strain which corresponds to its power of resistance. Also, it is more difficult to accomplish satisfactorily the connection of two different materials.

There appears to be no novelty in the American methods of fastenings. They consist of connections by pins and bolts with castings, which are of English origin. Hollow tubes for struts, long bundles of flat bars joined together for forming suspension chains, and iron rods for ties and secondary tension pieces, were long ago employed by the late Mr. Brunel on a large scale.

Comparing, nevertheless, free fastenings to the rigid connection of riveting, the former possesses the merit of making the work conformable to theory. Although plates or bars fastened by a number of rivets, and tightly pressed together, are not capable of pivoting freely, the ordinary calculations for lattice bars assume this freedom. This neglected rigidity, even after making allowance for the strains which tend to injure or to buckle certain parts, cannot fail to be a subsidiary reserve of resistance. The principal motive, however, which renders riveting so general in Europe is, that it makes use of the iron just in the state in which it comes from the rolling machines, without any forged eyes and screws being required. In consequence of the economy that results, it is

hardly to be expected that riveting will be superseded by bolts, except in rare instances when it might be necessary, at any cost, to lighten certain rods by enlarging them at their connection whilst leaving the ordinary section intact.

The difference of opinion on this particular point is analogous to that which exists between the supporters of drilling and punching rivet holes. Many German engineers insist on drilling, because they object to punching as liable to produce cracks in thin plates, or uneven holes in a layer of plates. These defects, however, appear to have been greatly exaggerated, as careful manufacturers produce satisfactory work by the economical method of punching. It would be desirable to retain certain distinctions between rough bridge work and the workmanship of delicate machines, caused by the difference in the methods employed. It is in fact essential to allow a higher coefficient of strain on ironwork with drilled holes than on ironwork with punched holes; for as long as all ironwork is subjected to a strain of 4 tons on the square inch without distinction, most manufacturers will adopt cheap ironwork, as so many girders constructed cheaply have on the whole lasted well.

With reference to this subject, the Charing Cross bridge,[1] designed by Sir John Hawkshaw, Past President Inst. C.E., may be cited as an instance of connections being made with large bolts. These bolts connect the lattice bars with the horizontal flanges, which are troughs made of wrought-iron plates and angle irons riveted together. The joint is therefore only partially free, as the natural rigidity of the flanges oppose a certain amount of resistance. The bolts made of steel, of diameters varying from 5 inches to 7 inches, have been adjusted, fitted, and screwed up, with great nicety. The work is certainly well done; but the Author is inclined to believe that Sir John Hawkshaw was influenced by the locality, and would not have adhered to the same system everywhere, which was very suitable in the centre of the metropolis.

The adoption, in the American system, of wide-apart lattice bars appears sound in principle, provided that the cross girders carrying the planking are not placed too far apart, and that the lattice bars, being stouter in proportion to the decrease in their number, have a sufficient area at their ends for inserting a proper amount of rivets, or eyes for very large bolts. The triangular Warren

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 512.

girder, introduced first in England, and of whic
Bordeaux, erected in 1858–60, furnishes an exa
is easily erected, inspected, and maintained. Th
being more concentrated, present less surface fo
little obstruction to wind.

Lastly, in proportion as the lattice girder is sim
subjected to the least strain are of a size large eno
unnecessary to increase the amount of material emplo
carried out in many trellis bridges with close lat
iron. Theoretically the close multiple lattice and t
gular framework would cost the same, as, when a ba
two, each of the parts merely requires a section hal
former. The condition of economy is contained i
inclination of the bars, and, as is well understood
angle should approximate to 45°. In America,
principle does not appear to be recognised, to juc
the most common types. The Author's opinion is
discussion on this subject, in 1863, at the Insti
Engineers.[1] The girders of Bollman, Fink, and oth
secondary tension rods approaching too nearly to
coupled to vertical struts, are not as strong as o
with an inclination of 45°, provided they are corr
and proportioned. M. Malézieux, however, states tha
can build bridges for one line of way and 197
about 12 cwt. of iron per lineal foot. This is a sati
but it is due, not to the so-called American syst
care taken in the design. In proof of this the Autl
attention to certain results obtained by himself
comparative des divers systèmes de Ponts en Fer'
On the next page are the values given in Table
book, in the case of bridges for two lines of way
girders spanning a single opening.

The weights for the simple triangular bracing a
than those for double triangular bracing or cross br
designs it was found expedient to introduce large
former system, for strengthening the connection of
to the flanges. No analogous calculations were ma
for a single line of way, but the data furnished in
this deficiency to be readily filled up. It is only ne
purpose, in Table XII.[A] relating to bridges with

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii.

	Height of the Girders.	Weight per Foot of Total Length.			Total Weight per Foot of clear Span.
		Two Main Girders.	Other Portions.	Total with $\frac{1}{10}$ added.	
	Feet. Ins.	Cwt.	Cwt.	Cwt.	Cwt.
Triangular girders. 16 feet 5 inches between centres of girders.					
Span 65 feet.	7 10½	4·68	3·36	8·84	9·24
Span 98 feet.	11 10	6·96	3·78	11·81	12·36
Span 131 feet. Girders acting as parapets	15 9	9·24	4·20	14·78	15·48
	15 5	8·70	4·98	15·04	15·72
Span 164 feet	19 8	11·22	5·28	18·15	18·96
Span 197 feet	22 11½	13·68	5·52	21·12	22·08
Span 230 feet	27 10½	17·40	5·88	25·61	26·76
Span 262 feet	31 2	21·00	6·12	29·83	31·20
Trellis girder. 16 feet 5 inches between centres of girders.					
Span 65 feet.	7 10½	4·50	3·36	8·65	9·00
Span 98 feet.	11 10	6·72	3·78	11·55	12·06
Span 131 feet. Girders acting as parapets.	15 9	8·88	4·20	14·39	15·06
	15 5	8·40	4·98	14·72	15·36
Span 164 feet	19 8	10·80	5·28	17·69	18·48
Span 197 feet	22 11½	13·20	5·52	20·59	21·54
Span 230 feet	27 10½	16·20	5·88	24·29	25·38
Span 262 feet	31 2	19·20	6·12	27·85	29·10

to take the two outer girders together with the half of the other portions. For instance, for a span of 197 feet with girders with cross braces, but without upright bars, the weights are:

	Cwt.
Weight of the two girders, 23 feet high	9·36
„ cross girders, rail bearers, wind ties, &c. .	2·64
Total weight per lineal foot	12·00

and with arched girders, attaining 36 feet in height at the centre:

	Cwt.
Weight of the two girders	8·40
„ other portions	2·70
Total weight per lineal foot	11·10

The details of the calculation already include a suitable provision for additions in practice, such as coverplates for the flanges,

enlargement of too slender bars subjected to compression, &c. If, notwithstanding, one-tenth is added to the weights, and if the weight per lineal foot is reckoned, not on the total length, but on the width of the clear opening (assumed to be $\frac{12}{13}$ of the length of the girder), the above weights, 12 cwt. and 11·1 cwt., will become 13·8 cwt., and 12·78 cwt. respectively. It is evident that the 12 cwt. mentioned by the American engineers for a span of 197 feet is approximately attainable without having recourse to their systems, especially if the additions for covers, &c., are reduced to a minimum, and if the depth of the girders is increased. The only remaining expedients by which the American system can attain a lighter weight would appear to be by subjecting the material to a greater strain, or by reducing the test load, or by the employment of bars enlarged at their points of connection, and consequently more costly.

It must, moreover, be borne in mind that, if bridges with several openings of 197 feet span are considered, the continuity of the girders will necessarily allow of a reduction in the weights.

It is essential to recollect, that, in these complicated questions, into which design and practice enter more materially than theory, too absolute generalisations must be guarded against. Each case requires a special and careful study, and design is of more importance than rigid principles. To decide between two designs for attaining the same object the mere matter of weight is not sufficient; it is necessary to see the drawings, which may perhaps reveal that the so-called economy of the one is due solely to reductions in the wind ties, rail bearers, &c. Lastly, the engineer who studies a design carefully, always, for one reason or another, intentionally allows a wide margin for additions in the actual construction which he is fully aware are not strictly required by theory.

Theoretical considerations alone, not fully worked out, are liable to lead to inaccurate conclusions. In an important work, "Statique graphique," by M. Maurice Lévy (pp. 146 and 147), there occurs this specious statement: that a triangular framework, having merely bars subjected to limited strains, is necessarily more economical than a girder subjected to flexion with neutral fibres. Taking the case of a girder with a solid web, which has neutral fibres, it would not be correct to say that theoretically such a girder would be more costly than a girder of the same height on the triangular lattice system. The solid web, which is very cheap, is substituted with great advantage for lattice bars for resisting the shearing strains. The so-called neutral central portion fulfils

a most important function, and practical men consider that, in addition, it assists somewhat to increase the moment of resistance. The flanges need not be taken into consideration, as they are the same in both systems.

In a part where the shearing strain is F, the theoretical mass of a solid web will be $\frac{F}{R'}$ per lineal foot of girder for a value R′ of shearing strain per square inch. With a lattice girder, with the bars inclined at the most favourable angle of 45°, the theoretical mass of the bars constituting the web amounts to $\frac{2\,F}{R}$ per lineal foot of girder, or double the amount of the solid web, if the shearing strain R′ may be reckoned at the same as the tensional or compressional strain R. This result is due to the fact that the solid web, in consequence of its continuity, fulfils at once the double function of tie and strut; whilst stretched in one direction at an angle of 45°, it can also be compressed at the same time in the contrary direction perpendicularly to the preceding strain; and to this double function, as before stated, another even is added, namely, the increase of the moment of resistance. Can this web plate, so marvellously utilised, be considered merely a neutral region, and an excess of material?

It must be understood that the Author has no desire to reinstate solid webs for girders of great height; the foregoing remarks are intended only to point out that practical considerations alone, not theoretical, lead to the preference for lattice bars for large spans. For small girders the solid web is decidedly superior.

In conclusion the Author would remark, that American engineers furnish splendid examples of boldness in their method of applying suspension cables to enormous spans, which, whether from timidity or want of opportunity, have not hitherto been attempted in Europe. In iron bridges generally they know how to avoid superfluous accessories, whilst, perhaps, increasing somewhat too much the cost of workmanship in cases where it might have been economical to have been contented with a more ordinary structure. The Author sees no great advantage in reverting to the combination of wrought and cast iron adopted by them from European models. Lastly, with reference to the so-called new or improved type of iron girders resting on abutments, there appears to be no reason for departing from the three great types of the Old World, namely:

(i.) The solid web-plate girder, due to Mr. Robert Stephenson, which must necessarily be restricted to small girders on account

of the number of stiffeners and cover plates which large girders of this kind require.

(ii.) The bowstring girder, due to Mr. Brunel, complicated in structure, but specially applicable to large spans.

(iii.) Lastly, and specially, the lattice girder with bars inclined at an angle of 45°, which theoretically is the same in cost whether the lattice bars are close or far apart, but in which the spacing of the bars must depend on practical considerations, such as size, the distribution of the loads, and the best arrangement of the connections.

To sum up, if Europe is more scientific than the New World, it is perhaps less bold. When European engineers relinquish numberless secondary excesses of strength, they will attain by their own systems to the utmost limits of lightness and economy. Doubtless necessity will urge them to this course if, in their turn, they adopt larger spans than those they have hitherto found sufficient; but, on the other hand, an excess of strength is not without its advantages.

Stability of Arches.

The stability of masonry arches has for a long time exercised the ingenuity of mathematicians, and it may be considered that the discussion on the subject has been exhausted. The Author, however, believes that a comparison of the points of view of the three writers who have published their valuable investigations on the subject may not be without interest.

One of these writers, M. de Perrodil,[1] gives the results he has arrived at in the case of an arch, built of ashlar masonry with cement mortar, considered as a monolith, elastic, and allowing of tensional strains.

Another, M. Williot,[2] furnishes a practical investigation based upon Moseley's theory of the principle of least resistance.

Lastly, the late Inspector-General Dupuit, in his posthumous work on the equilibrium of arches, repudiates entirely the principle of least resistance, and relies on the movement the arch undergoes at the instant when the centres are removed.

There is no need to recall the reasons of this disagreement, or the differences in the points of view. It is well known that if three points are given in a curve of pressures, or if, for example,

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[1] *Vide* "Annales des Ponts et Chaussées," series 5, vol. xi., p. 178.

[2] *Vide* "Annales du Génie civil," June 1872.

an arch on three pivots is under consideration, no doubt can arise as to the tracing of the forces, as it is merely a problem of elementary statics. But with a number of surfaces of contact at the joints, the three determining points cannot be arrived at by simple statics.

According to Méry they depend on the settling; and this view was taken up by Dupuit on a better investigation of the subject. Moseley's theory, whilst giving results coincident with the effects of settling as regards the lower points, tends to raise the curve of pressures at the crown. The term settling can be employed without admitting all the consequences which Dupuit assigns to it, as it is acknowledged that there is a certain compression which prevents the forces keeping absolutely to mathematical lines. Also the partisans of the removal of the centres theory, and those who hold to the theory of equal resistance, have this in common, that they do not take into account the adherence of cohesion in the arch stones, but consider friction alone as preventing sliding.

M. de Perrodil has proceeded very differently in his article already referred to. Investigating the trial arch at the Souppes quarries near Paris, built of well-dressed arch stones set in cement, it occurred to him to calculate the arch as a monolith possessing a power of resisting extension in all its joints. But it is evident that he was animated much more by mere curiosity to investigate a peculiar case, more or less theoretical, than by the desire of laying down a systematic theory. Moreover, he acknowledged that a small crack which appeared in the Souppes arch, at the extrados of the joint at the springing, overthrows a portion of the hypothesis taken as the basis of his calculations. These calculations also indicated a tensional strain of 625 lbs. per square inch—an unheard-of strain for masonry, however excellent it may be. M. de Perrodil's calculations are not essentially wrong in themselves, but their application to structures formed of stone and cement is inadmissible; with other materials they might be correct. The Author, however, does not propose to reproduce this theory, which, moreover, does not differ from that of elastic iron arches; but it is desirable to show how it happens that it is not indeterminate. If it was only necessary to consider the thrust at the crown, this point would be determined, as in the case of an iron arch supported on masonry pivots, by the condition that the general deformation maintains the chord of the mean fibre unaltered. Next, since in fact the points at the springing are not given, they can be determined on the hypothesis of their

being built into the abutments, that is to say, that these joints cannot open, being kept in place by molecular tensions, and that the plane on which they are fixed is unalterable. There is consequently no necessity to bring in the subsidiary principle of least resistance, as everything is determined beforehand. The arch, resting on its centres, might be considered as not subjected to pressure. The motion on removing the centres is neither contradictory, nor incompatible with the other conclusions. When the centre is gradually removed, the arch settles to the extent required to develop the tensional and compressional strains which the calculations of elasticity assign.

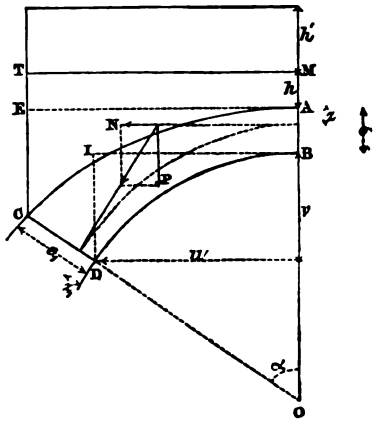
Returning to the ordinary hypothesis of stone voussoirs, that they are without adherence, and consequently liable to turn on their edges in opening their joints without resistance, and admitting an uncertainty in the position of the centre of pressure at certain closed joints, the Author is of opinion, with reference to such arches, that the choice lies between the principle of least resistance and the theory based on the rotation caused by removing the centres.

It may be remarked that these two principles lead to the tracing of curves of pressure, which are limited as nearly to certain edges as the resistance of the material will allow; and it is only in some measure the initial crushing which forces the curve to retreat a little within the joints. It is therefore necessary to give up the notion of Méry and other writers, who imagined that they might limit to any desired extent the strain on the joints by choosing suitable thicknesses. Some of the joints would undoubtedly crush if this was not prevented by their somewhat rounded or obtuse edges, and more particularly by the bed of mortar, which in crushing tends to send the centre of pressure further within the joint. It must, however, be added that the arbitrary rule of M. Méry would lead to no harm in its application, as its defect is rather to exaggerate to a too vague extent the excess of the dimensions desirable in practice.

By the principle of the least thrust, the curve of pressures tends to touch the extrados at the crown, and the intrados towards the haunches, or at the springing, in such a manner that it remains within the masonry with the absolutely necessary compressive play. Other writers before M. Williot, and more particularly Mr. Scheffler, have admitted this starting point; but the Author proposes to borrow from M. Williot a method of calculation which, with slight modifications, may prove of value, even whilst surrendering the principle of the least thrust.

Considering the arc (Fig. 1) comprised between the crown A B and the joint of rupture C D, and admitting that the arc B D of the intrados is approximately an arc of a circle whose radius is $\frac{u^2 + v^2}{2v}$, a function of the half chord u and the versed sine v of this piece of arch; and let A B = e, C D = e_1, and the B O D = α; let π be the weight of the voussoir A B D C per cubic yard, and also of the rectangle A M T E, consisting of embankment or metalling, whose height h is understood to be reduced to the density of the masonry; and let π' be the weight per cubic yard of the earth contained in the curvilinear triangle A E C; if, moreover, it is assumed that this area A E C is approximately equal to the area B I D, the weight P of the portion M B D C T may be taken to be approximately $\pi [(h + e) u + (h + v) e_1 \sin \alpha] + \frac{\pi' v}{3}\left(u - \frac{2v^2}{5u}\right)$; and neglecting the functions of e or e_1 of the second order, the moment of this weight referred to the axis A O is,

Fig. 1.



$$\mu = \pi \left[u^2 \frac{h + e}{2} + u (h + v) e_1 \sin \alpha \right] + \frac{\pi' v}{4}\left(u^2 - \frac{v^2}{3}\right).$$

Then an investigation of the permanent curve of pressures furnishes the following equations:

The equilibrium of rotation between P and the thrust N of the key with reference to the centre of pressure at the springing, this centre being situated at a short distance z_1 from the edge D, gives,

$$P (u + z_1 \sin \alpha) - \mu = N (v + e - z - z_1 \cos \alpha) \quad . \quad . \quad (i.)$$

The limited compressive strain R developed on the edge D gives,

$$P \sin \alpha + N \cos \alpha = \frac{3}{2} R z_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (ii.)$$

And for the same strain at A, the centre of pressure being assumed at a distance z from A shorter than $\frac{e}{3}$,

$$N = \frac{3\,z\,R}{2} \quad . \quad . \quad .

If the value of h' is given instead of the proportion $\frac{N'}{N}$, the equation for determining e will be,

$$e^2\left[\left(\cos\alpha+\frac{2v\sin\alpha}{u}\right)^2-1\right]=e\left(2v-\frac{\pi u^2}{R}\right)-\frac{u^2}{R}\left[\pi(h+h')+\frac{\pi' v}{2}\left(\frac{1}{3}-\frac{v^2}{5u^2}\right)\right],$$

and

$$\frac{N'}{N}=\frac{v+e}{v+\frac{e}{2}-\frac{R e_1^2+u^2\pi h'}{2Re}}.$$

If this last equation for e has real roots (that is to say, if the value assigned to h' furnishes a possible solution) the two roots will be positive, and that root must be selected which, when substituted for e in the equation for $\frac{N'}{N}$, gives an admissible value for this proportion. The value of e_1 is calculated from the equation previously given.

Lastly, it is easy to obtain the values, $N' = R\,e$, $z=\frac{2N}{3R}$; $z_1=\frac{2}{3}\frac{P\sin\alpha+N\cos\alpha}{R}$, and to trace the permanent and final curves of pressure, the prolongations of which will be useful for the investigation of the parts below the joint of rupture.

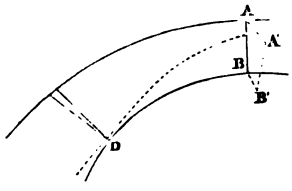
The object of this method is to determine the principal thicknesses of an arch without resorting to a tentative process. The elements of the joint, although successively extremely compressed or crushed, are however considered to continue their resistance to compression within the limited value of R, whilst the centre of pressure recedes: if, on the contrary, these were relieved bit by bit from all cooperation in resisting the strains, the failure of the arch would be accelerated.[1]

The Author next proposes to investigate the theory which determines the line of the curve of pressure from the effects pro-

[1] It should be noted that if the maximum stress R supported by the substance of the arch is considered as given, the strict widths to which the joints of the masonry may be limited may be obtained graphically, by the process of M. Durand-Claye, of which the principle is given in the Minutes of Proceedings of the Inst. C.E. vol. xxxi., p. 78, further developed by M. Gobert in the "Mémoires de la Soc. des Ing. civils," Paris, 1878, p. 428.—J. G.

duced on removing the centres. This operation generates a thrust which did not previously exist; the two semi-arcs, or voussoirs, which have to butt against each other at the crown, fall towards each other till their compression produces the resisting reactions. This fall is a movement of rotation which selects the easiest axis to turn on, namely, the edge of the intrados of the joint of rupture, or what may be termed the hinge-point. The dynamical curve with varying pressure, investigated by Dupuit, which is produced in different phases of the motion, and where the force of inertia intervenes, goes always to the hinge-point, even when, owing to the motion acquired, the position of equilibrium is passed. Provided that the impulse does not extend far enough to open other joints, so as to produce a complete dislocation, it slackens of itself, owing to the reversed action of the forces of inertia. After some oscillations equilibrium is established, with a definite reaction always concentrated towards the hinge-point; and the joint of rupture gapes inevitably at the extrados, although frequently to an imperceptible extent, especially if it is distributed amongst several joints. The definite curve of equilibrium must therefore touch the intrados at the point of rupture, as the theory of the least resistance indicated; it is, however, at the crown that the divergence occurs. It might happen in certain cases that at this latter joint the curve would rise nearly up to the extrados; but this could only be due to a settlement of the abutment or of the hinge-joint, and not at all owing to the least resistance—a rigid principle which is assumed to determine everything *à priori*, without any relation to the care taken in execution. The goodness of the work must have some bearing on the subject; it introduces an undefined, restricted, but nevertheless real effect, which precisely affects the rise of the curve at the crown. In arches with the ordinary profiles, the centre of pressure at the summit is situated about the centre of the joint; for when the arch turns on D (Fig. 2), the arc A A′ described by A is a little larger than the arc B B′ described by B; the figure of compression A A′ B′ B is a kind of trapezium, the centre of gravity of which indicates a resultant nearer to A than to B, even when the hinge-point is assumed to be fixed, and which must rise more if D recedes.

FIG. 2.



The curve of equilibrium (shown by a dotted line in Fig. 2) starts from a somewhat undefined point between A and the

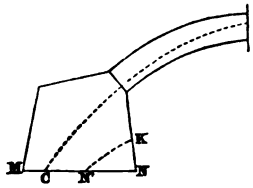
centre of A B, and nearly touches the intrados towards the point of rupture D, which point is situated at the springing in the segmental arches, and approximately at the level of the centre of the rise in semicircular or elliptical arches. Although this curve indicates a high pressure at D, and eventually at A also, the equilibrium is nevertheless ensured by the sole conditions that neither between A B and D, nor below D, does any portion of the curve pass out of the solid masonry, or approach near enough to the edges of the extrados to cause the production of other inverse hinge-points which would involve a complete dislocation.

If the pier is sufficiently stable to prevent any motion at D, the voussoir D A and its counterpart cannot fall unless the material of which they are built is too weak to stand the pressure and fails by crushing. As most kinds of stone are strong enough to satisfy this requirement in the case of the spans commonly adopted, the arch itself, according to this theory, does not need to be investigated with reference to crushing; but it is sufficient merely to ascertain the equilibrium of rotation by an approximate tracing of the curve. From this point of view, it may sometimes be more advantageous, as regards resistance, to reduce rather than to increase the thickness of the arch, because the forces at work are thus at any rate diminished, whilst their centre of action at D cannot be improved.

The case is different as regards the lower portions and the piers, as with them, by increasing the thickness, the limit of the pressures can be reduced to any given value; but on this subject the Author wishes to refer to an observation made by Dupuit:

Let it be assumed that the curve, prolonged, ends on a course M N (Fig. 3), in a point C, the distance of which from the edge M is less than $\frac{1}{3}$ of M N. It is customary in such a case to calculate the maximum pressure at M on the hypothesis that the bearing surface is reduced to $M N' = 3 M C$; the pressure being nothing at N', and increasing lineally up to M, whilst the other part of the joint N' N opens. But when once a fissure is supposed to be formed, is it certain that it will occur along N' N? It appears more logical, and in any case more probable, that a sloping crack like N' K would take place, which avoids the raising of the mass N K N'. This mass will thenceforward be severed from the weight which served to fix the point C, which will approach nearer to M, and might even require

FIG. 3.

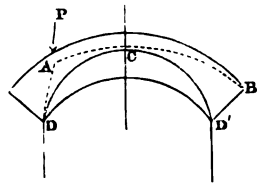


a fresh correction in the event of a larger block than N K N′ being detached.

The Author now proposes to revert to the work of Dupuit for the purpose of investigating various particular cases.

In ogee arches the accidental points of failure at the edges of the extrados are liable to occur near the top of the haunches of the arch, instead of in the piers, and the joint of the key opens then at the extrados. The advantage of loading the summit of the ogee so as to close the joint is well understood. In like manner, in the case of the ordinary types of arches, a surcharge placed over the abutments, or the haunches, sometimes affords an efficacious remedy against failure; usually, putting on an additional surcharge stretches or stiffens the curve, forming a buttress at the part loaded. Thus, for example, the curve of equilibrium, which originally was D C D′ (Fig. 4), may become D A C B under the action of a surcharge P; the portion C B, at first symmetrical with C A, continues its course without deviation, and the original hinge-point D′ travels towards the extrados B, which may lead to rupture by raising the voussoir on the right, and by lowering the central thrust C at the crown.

FIG. 4.



Accordingly, subsequent alterations may do away with the original hinge-points; and it may be asked whether, the alterations being removed, the relapse into the original situation will re-establish exactly the former state of things. There may be a certain amount of indecision in this matter, but it appears on the whole that the various deductions drawn by Dupuit are well reasoned out, and should unite all views; whilst in the principle of least resistance applied to arches, there appears to be a sort of pre-determination, and a decision as to the equilibrium arrived at. The promoters also are always ready to relinquish their principle in certain instances which would involve its immediate overthrow; as if a great law should possess this compliance, and nature were solicitous as to the stability of the scaffolding.

As a practical conclusion, since the thickening of an arch, instead of remedying may even aggravate the concentration of pressure at the joint of rupture, is it necessary to give up the idea of constructing arches with very great spans? and has the instinct or experience of engineers led them to stop at the limit which, having regard to the strength of the materials at their command, it would be unwise to overstep? This is not likely; but certain

precautions must be taken which have already been more or less practised.

Besides rough dressing and chamfering the stones, which corresponds to rounding off the edges, Perronet showed the advantage of omitting to put mortar between the joints a few inches from the faces of the stones, and filling the void with oakum. Another additional precaution, frequently adopted, consists in making the joints thicker where they tend to close, which moreover increases the extent of contact when the mortar is compressed. In the Grosvenor bridge at Chester,[1] of 200 feet span, the protecting cushion consisted of sheets of lead, which yielded to the pressure. It is evident, moreover, that the employment of very hard materials at the point most liable to crushing is dictated by common sense; and the variety of appearance occasioned would be pleasing to the eye. The architect ought, in fact, to embrace every opportunity of variety which might add to the strength of an edifice, and ought no more to hide the parts which strengthen it, than a sculptor would conceal the limbs and muscles of a statue.

The precautions which have been just mentioned are merely rudimentary expedients. The real remedy, applicable to the largest arches, would be to carry out an idea of Dupuit of making actual pivots, bringing back the thrust to the centre of certain joints, and producing the same coincidence at all the other joints by means of a suitable profile given to the intrados. It would scarcely be necessary for this purpose to use iron blocks. The pivoting joint must be bevelled considerably at the side where closing occurs, so that the removal of the centres makes the voussoir roll slightly on an obtuse central boss, protected in addition, if necessary, by lead or oakum. The centre of pressure will be very nearly kept to the desired point, and, after the settlement has stopped, the openings in the intrados and extrados can be filled with cement. Since the pressure would thus be concentrated at the centre, even if the extent of surface is small, it is much less dangerous than if it acted at the edges; for the manner in which the crushing load is stated per square inch, without any reference to the situation of the various points under compression of the bearing surface, is purely conventional.

Dupuit, lastly, takes up and improves a curious project of Perronet, relating to a stone arch of 525 feet span. Iron structures, on

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[1] *Vide* Transactions of the Inst. C.E., vol. i., p. 207.

account of their lightness, are preeminently suitable for large spans; whereas, on the contrary, the cost of large masonry arches is increased by their enormous weight, and by the difficulties attending the scaffolding; and engineers can never sacrifice economy for the sake of an idea. Nevertheless, it would be a great thing to accomplish—not Perronet's dream, but the erection of an arch of 300 or 350 feet span in ashlar masonry; and the engineer who should be in a position to achieve such a result might, by the exercise of some ability, render both his own name and the site of the work illustrious.

The communication is illustrated by several small scale drawings, from which Plates 7 and 8 have been compiled.

No. 1,642.—"Note on a Graphic Mode of ascertaining the Flow of a Mill Stream." By WILLIAM SHELFORD, M. Inst. C.E.

THE fluctuations in the flow of many streams on which water-wheels are employed, the disturbing causes due to the irregular working of the mills and to the storage of the water in the mill ponds, combined with the great accuracy required in gauging comparatively small quantities of water, create considerable difficulty in estimating the discharge, and make a complete series of observations for that purpose very costly.

In such a case a successful result was lately arrived at in the manner illustrated by the accompanying diagram (Plate 9), under the following circumstances:

It became necessary to ascertain with some degree of precision what was the mean dry-weather flow of a small mill-stream, in the county of Kent, the water of which was much prized, and it was desired to effect this at the least possible cost. The observations were accordingly commenced at the end of June, and were continued till the autumn rains set in, at the end of October, or four months in all. A carefully-constructed gauge, with a copper notch-plate, was fixed at a point where the flow was always free, above which there was a mill having an extensive reservoir, or mill pond. It was soon found that the stream presented irregularities which would defy gauging, unless observations were taken hourly; while the continuation of these for four months would be certainly expensive, and the result might be unreliable. It was therefore determined, after a few preliminary gaugings, 1st. To obtain from the miller a daily return of the time of starting and stopping the water-wheel, and the height at the same hours of the water in the pond; and 2nd. To employ one intelligent man to observe the gauge at four convenient times in the twenty-four hours, viz., about 6 A.M., 1 P.M., 6 P.M., and 10 P.M. The returns were signed, and forwarded daily on printed post cards, and any symptom of slackened interest or delay was thus noticed immediately. The figures so supplied, when plotted on the diagram, showed the reason for each fluctuation on the gauge, and gave an opportunity of detecting errors, and (on the larger scale) of rounding off angles, thus furnishing as exact a representation of the actual flow as could have been obtained by more frequent observations. When the diagram was completed, the average flow for each six hours was ascertained by

scaling, and thence the mean flow of the stream for any period was obtained. In the diagram the scale has not only been reduced, but the lines have been drawn straight between the points, and only the two driest months are illustrated. It will, however, suffice to show the method employed.

The Paper is accompanied by a drawing from which Plate 9 has been engraved.

MEMOIRS OF DECEASED MEMBERS.

. HENRY ORLANDO BRIDGEMAN, the eldest son of the n. and Rev. H. E. Bridgeman, was born at Blymhill, Shropre, on the 26th of January, 1825. After a course of private tion, he was for about three years at the College for Civil gineers, Putney. He then entered the office of Mr. Charles dell, and became an assistant engineer on a portion of the ton and Peterborough railway. From 1848 to 1850 he was ployed under Mr. John Fowler, Past-President Inst. C.E., as stant resident engineer on the Leverton to Lincoln extension the Manchester, Sheffield, and Lincolnshire railway, which braced the Torksey bridge over the Trent, the subject of an imtant discussion at the Institution[1] in the year 1850. This was early example of a tubular girder bridge, and the Inspecting icers of the Board of Trade had expressed doubts as to its ultimate ty and security. The results of a mathematical investigation Mr. Pole, M. Inst. C.E., confirmed by experiments on a large le conducted by Mr. C. H. Wild, demonstrated the increase of ngth due to the continuity of the girder over the centre pier, led to the sanction of the Railway Commissioners for the ning of the line being given after a delay of four months. . Bridgeman was then engaged upon Parliamentary work and veys for new railways, namely, the Oxford and Brentford, the rcester and Hereford, the London and Mid-Kent, and the pping Norton, in England; and the Rheims and Douai in nce. From 1852 to 1856 he was the acting engineer under Messrs. der (Past-President, Inst. C.E.) and Mr. Fowler, on the London, bury, and Southend railway. On the opening of this line he s sent by Mr. Fowler to Algeria, where he was employed upon surveys of the Philippeville and Constantine railway. On his rn to England, in 1858, he took charge of the construction of Severn Valley railway, also under Mr. Fowler, where he ained till 1862. From this period he occasionally assisted Bidder and other engineers in estimates for Parliamentary osition, and in investigating projects in foreign countries; but health failing, he was obliged to withdraw from the active

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., pp. 233–287.

pursuit of the profession. His death occurred suddenly, on the 14th of June, 1879, extensive disease of the lungs and weakness of the heart being the cause.

Mr. Bridgeman was elected an Associate of the Institution in December 1849, and was transferred to the class of Members in February 1855.

MR. WILLIAM WHITAKER COLLINS, son of the late Mr. William Young Collins, who for many years held the appointment of accountant at Messrs. Maudslay's, in Lambeth, was born in London on the 11th of February, 1817. After completing his education he served a regular apprenticeship to the firm of Messrs. Maudslay and Field, and was employed for some time in the drawing office. His next engagement was under Sir Marc Isambard Brunel, M. Inst. C.E., at the works of the Thames tunnel, where he was associated with the late Mr. Thomas Page, M. Inst. C.E. From thence he went to the factory of Messrs. Rennie, where he remained for three years, designing machinery and prosecuting other engineering work. His next appointment was that of resident engineer to the Société d'Ougrée, in Belgium, afterwards becoming consulting engineer to the works of Messrs. Cockerill and Co., of Seraing. Here he remained for several years, after which he returned to England, and was employed on the construction of the London docks under Mr. Smeaton.

In the year 1847, that is to say at the age of thirty, Mr. Collins commenced to practice on his own account as a civil engineer. About ten years later he entered into partnership with Mr. T. R. Crampton, M. Inst. C.E.; and it was during this partnership that he, in conjunction with Mr. Crampton, designed and carried out the extensive waterworks for the city of Berlin, as well as several other enterprises of an important character. The partnership lasted about eight years, and at its termination Mr. Collins resumed practice by himself, retaining the same offices, in Buckingham Street, Adelphi, until he retired a few years before his death.

Mr. Collins was elected an Associate of the Institution of Civil Engineers in the year 1846, during the presidency of his old master, Sir John Rennie, and became a full Member of the Institution in the year 1860, when Mr. Bidder was President, his certificate bearing the following well-known names: Joshua Field, Joseph Cubitt, John Fowler, Hamilton H. Fulton, Thomas Page, T. Macdougall Smith, John Rennie, Charles Hutton Gregory, James Simpson, Henry Maudslay, Charles Fox, S. C. Homersham, and T. R. Crampton.

Mr. Collins was well known to most of the leading members of the profession, and had a large circle of private friends. He was for many years a regular attendant at the meetings; and as he had the misfortune in comparatively early life to lose his leg, through an accident which was considered but trifling at the time, necessitating ever after the use of crutches, his form and face were conspicuously familiar to those who, like himself, attended the evening discussions. Having been during the whole of his life a great reader, and possessing a good library, and an exceptionally brilliant memory, he had at his disposal an inexhaustible store of professional information, which he was always ready to impart to others; and the uniform kindness and geniality which the younger members of the profession invariably received from him will make his name long remembered with gratitude and with pleasure. The freedom, however, with which he communicated information upon general and professional subjects bore a striking contrast to his great reticence with respect to personal matters connected with himself, about which his most intimate friends knew but little more than strangers.

Mr. William Whitaker Collins, besides being a Member of the Institution of Civil Engineers, was a Fellow or Member of the following scientific bodies: the Geological, Royal Microscopical, Meteorological, and Zoological Societies, as well as of the Royal Institution and the British Association. He died at Brompton, somewhat suddenly, from bronchitis, on the 15th of March, 1879, at the age of sixty-two, and was interred at the West London cemetery on the 22nd of the same month.

Mr. JOHN SYDNEY CROSSLEY was born at Loughborough, in Leicestershire, on Christmas Day, 1812, and was left an orphan when only two years old. At an early age he was articled by his guardian, Mr. Staveley, architect, of Leicester, to that gentleman's son, Mr. Edward Staveley, then engineer to the Leicester Navigation Company. In 1832 Mr. Edward Staveley went to America, and Mr. Crossley was appointed engineer to the Canal Company—a connection that continued, first as engineer, and afterwards as a director, up to the time of his death. Mr. Crossley's experience on railway work commenced in 1832 and 1833, when he was engaged under the late Mr. W. A. Provis, M. Inst. C.E., upon the parliamentary surveys of the Leicester and Swannington railway. In 1835 he was employed under the late Mr. Vignoles, Past-President Inst. C.E., in connection with the preliminary work for the Midland Counties

railway. After this he was not again associated with railway work until 1845, when he was occupied on the surveys for the South Midland railway. In 1846 Mr. Crossley was concerned in the parliamentary work of the Leicester and Swannington extension of the Midland railway, under Mr. Charles Liddell, the engineer-in-chief; and subsequently on the construction of the line from Ashby to Coalville, of the deviation from Coalville to Leicester, and of the stations from Burton to Leicester. The carrying out of these works lasted until 1851, when Mr. Crossley was engaged under Mr. Hawksley, Past-President Inst. C.E., for the Leicester Waterworks Company.

In September 1852 Mr. Crossley commenced the surveys of the Leicester and Hitchin branch of the Midland railway, the parliamentary plans for which were deposited in that year; but, owing to the intense application bestowed on this work, on the 30th of November, 1852, he was seized with a paralytic stroke in Mr. Charles Liddell's office, and his state was considered hopeless for some time. Careful nursing, however, brought him through this illness, and in September 1853 he had so far recovered, that he was able to assume the position of resident engineer on the Leicester and Hitchin railway, under Mr. Charles Liddell. The carrying out of the works on this line were not completed until 1857, when Mr. Crossley was appointed resident engineer to the Midland Railway Company, which led, in 1858, to his becoming engineer-in-chief to the same company. In addition to discharging the duties of maintaining the permanent way and stations, Mr Crossley was engaged in obtaining parliamentary powers for, and in responsible charge of the execution of the works of, the following lines and branches for the company: The Erewash Valley extension from Pye Bridge to Clay Cross; the Cudworth and Barnsley, Duffield and Wirksworth, Mangotsfield and Bath, Yate and Thornbury, Derby, Melbourne, and Breedon and Ashby, Stenson and Weston, Mansfield and Worksop, and the Ambergate and Codnor Park branches; the Trent and Derby curves; the Radford and Trowele branch; the Bristol Junction lines; the Gloucester to Berkley new docks; the Trent to Leicester widening; the Shipley and Guiseley branch; and the Settle and Carlisle railway—constituting in all about 225 miles of passenger lines, in addition to colliery branches, junction curves, brewery lines at Burton, and sundry minor works. The capital expended on these lines and branches has been estimated at between seven and eight millions sterling. Besides the works over which Mr. Crossley had direct control, there were many undertakings of which he was joint engineer; among these may be mentioned the Otley and

Ilkley, the Ashby and Nuneaton, the Cheshire lines, and the Furness Extensions railways. Of all these, the greatest engineering work was the Settle and Carlisle railway, 72¼ miles in length. This had to be made through a difficult country, at great disadvantages, owing to the bad climate, the scanty population, and the absence of labour in the district. This most important branch of the Midland railway was, however, opened for passenger traffic on the 1st of May, 1876, when the directors of the company testified their satisfaction at the way in which the work had been carried out by presenting Mr. Crossley with a handsome gift, and by appointing him joint consulting engineer to the Company, on resigning the office of chief engineer in April 1875. About the same time he was also elected consulting engineer to the Leeds and Liverpool Canal Company.

During the later years of his life Mr. Crossley was only engaged on occasional work for railway and canal companies. Noted for indefatigable power of will, for the utmost exactitude in all details, and for his perfect honesty of intentions and fairness in action, his services were simply invaluable. His success was entirely due to his own exertions, and to a power of attaching subordinates to him, so that with their loyal assistance he was enabled to overcome all difficulties in carrying out the many works of which he had charge. In the committee rooms Mr. Crossley was well known as a witness; and an eminent counsel, now on the Bench, expressed his regret, to a mutual friend, that his promotion prevented him from having any further encounters with Mr. Crossley before a committee. He died at his residence at Barrow-upon-Soar on the 10th of June, 1879.

Mr. Crossley was elected a Member of the Institution in 1859; he was also a Fellow of the Geological Society, and a Member of the Society of Arts.

Mr. JOHN CURPHEY FORSYTH was born on the 14th of July, 1815, at Picton Castle, Pembrokeshire, one of the seats of the first Lord Milford. His father, Mr. John Forsyth, was in that nobleman's service, but subsequently was employed on the works of the Liverpool and Manchester railway, under Mr. George Stephenson, and after the completion of the line remained with the company until killed, in December 1844. The son was brought up under the auspices of Mr. John Dixon, and in 1834 the duties were assigned to him of sub-resident engineer on the portion of the line between Newton and Manchester. About

the year 1837 he was placed at the head of the office of Mr. T. L. Gooch, M. Inst. C.E., in Manchester, when the contract drawings were being made for the unusually heavy and extensive works of the Manchester and Leeds railway, for the execution of which Mr. George Stephenson and Mr. Gooch were the joint principal engineers; and he had charge of the preparation of these drawings until the works of the whole line were let and under contract. Afterwards he was appointed resident engineer for the construction of a section of 7 or 8 miles of the main line including several large bridges, in the neighbourhood of Huddersfield, where he remained until the line was opened to the public, early in 1841. Here he exhibited considerable engineering talent, and displayed the most untiring industry, combined with accuracy and decision. From 1841 to 1843 Mr. Forsyth was in Manchester, and again held the post of resident engineer under Mr. Gooch, in the construction of an important extension of the Manchester and Leeds railway into the heart of Manchester, to meet a similar extension of the Liverpool and Manchester railway through Salford. He had likewise placed under his charge, at the point of junction of these two extensions, the erection of the whole of the joint central station there, now known as the Victoria Station. These extensions supplied the only link wanting to complete a continuous railway communication from Liverpool to Hull, and their importance at the time could hardly be overrated. They were opened to the public on the 1st of January, 1844. Mr. Forsyth was then engaged in preparing the plans for various branches of the Manchester and Leeds railway, and in giving evidence on the same before parliamentary committees. In January 1845 he became an assistant to Mr. Gooch in London, and was similarly occupied in relation to several proposed railways for which Mr. Gooch was acting as principal engineer, viz., the Trent Valley (Act obtained); the Leeds and Bradford extension to Skipton and Colne (Act obtained); the Blackburn, Burnley, and Colne, afterwards called the East Lancashire (Act obtained), and the Southport and Euxton (Bill thrown out). Mr. Forsyth had by this time earned the character of being an excellent sample of a resident engineer to take charge of work, having a good practical notion of the way it should be carried on, with determination and energy to see that it was done promptly and thoroughly. In the autumn of 1845, at the request of the late Mr. G. P. Bidder, Past-President Inst. C.E., he was engaged to assist in the preparation of the plans for the proposed North Staffordshire railway, for which the late Mr. Robert Stephenson, Mr. Bidder, and Mr. Gooch were the joint principal engineers, Mr. Bidder taking the active part

n that line, as Mr. Gooch did, under a similar engineering arrange-
ent, in the case of the Trent Valley. The Act for the North
affordshire was passed in 1846, when Mr. Forsyth was appointed
sident engineer to a large section of the line, and had charge
f the construction of that section, which was wholly or partially
ened in 1848, and he remained as the resident engineer for the
ilway company, taking charge of the entire line on its comple-
ion, including the canal belonging to the company, until 1853.
n that year the then manager, the late Mr. S. P. Bidder, resigned
hat appointment to go to Canada, when, after great pressure and
rith much reluctance, Mr. Forsyth was prevailed upon to accept,
t a small increase of salary, in addition to his position of engineer,
hat of manager, and he held the two appointments until 1864,
hen he resigned both offices. On this occasion he was presented
rith a testimonial by the members of his staff, and with another
y his friends the traders of the district, and he was appointed
onsulting engineer and engineer for the construction of new lines,
o that the company did not lose entirely his valuable services,
nd both of these appointments he held until his death. During
his period the following lines and branches were made, viz., the
eek, Macclesfield Bollington and Marple joint line of the North
affordshire, and Manchester Sheffield and Lincolnshire Railway
ompanies; the Silverdale, Madeley, and Market Drayton; the
udley, Newcastle, and Silverdale widening; and the Potteries
op line. When these lines were under construction his health
iled, and he was obliged to be absent from business for several
onths together, but with the assistance of his brother, Mr. Joseph
'orsyth, whom he took as pupil in 1857, the works he had in
and were completed.

Mr. Forsyth was elected a Member of the Institution of
ivil Engineers in 1853. He was also a Member of the Institution
f Mechanical Engineers, and a Fellow of the Royal Microscopical
ociety. He was a man who had thoroughly at heart the interests
f those whom he served. He died on the 15th of February,
879, at his residence, Marsh House, Newcastle-under-Lyme, deeply
egretted by all, especially by those who had served under him
or so many years on the North Staffordshire railway and canal.

R. THOMAS SOPWITH, M.A., F.R.S., was born at Newcastle-
n-Tyne, on the 3rd of January, 1803. He was the only son of
r. Jacob Sopwith, an extensive cabinet-maker in that town. He
as educated at private schools in Gateshead and Newcastle, and

duly apprenticed to his father, whose business was then, and had been for many years, large and prosperous. In early life he evinced much taste for drawing, and for scientific and literary pursuits; and was remarkable for great industry, early rising, and perseverance in the acquisition of technical knowledge in all that related to the mining districts and to the practice of surveying. When eighteen years old he commenced to keep a diary, or journal, and for fifty-eight years, viz., to January 3rd, 1879, he systematically and carefully recorded the incidents of his life and local and general events. These diaries comprise one hundred and seventy volumes, written in the most beautiful and legible style; and from them the greater portion of this notice of his life and labours has been taken. At this time he worked at the bench from 6 A.M. to 6 P.M., and frequently till 8 or 9 at night; but still he found intervals of leisure to study architecture, and the use of optical and philosophical instruments. In 1822 he prepared plans and drawings for a new gaol for Newcastle, for one hundred and eighty-four prisoners, and afterwards a plan for one hundred and twenty-five prisoners, illustrated with drawings and models; and for these, and his clear and fluent explanations, he was complimented by Mr. John Bell, the Mayor, and Mr. John Clayton, the Town Clerk, and the sum of ten guineas was voted to him by the committee. When twenty-one years of age his father consented to allow him to leave the business, and to engage himself to Mr. Joseph Dickinson, mining and land surveyor, of Alston, who was then employed in surveying the lead-mining properties of the Commissioners of Greenwich Hospital. In 1826 he made and published two plans of the interior of All Saints Church, Newcastle-on-Tyne, with historical and descriptive notices, and he became a member of the Eclectic Society of Newcastle. Mr. Dickinson at the end of the first year took him into partnership, giving him one-third of the profits of the business; and for four years he was engaged in surveying at Alston and the neighbourhood. He was sworn a burgess, and admitted a freeman of Newcastle, on the 20th of October, 1823, and his certificate, signed "Wm. Wright, Mayor," and "Clayton, Town Clerk," is carefully preserved. He also records that, "having taken the oath and kissed the Testament, he was instructed to kneel on the right knee, and present the mayor with a silver coin," and thus became a "freeman." The fees paid by him on this occasion amounted to £2 6*s*. 11*d*.; and he observes that the fees paid by his father in 1792 were only £1 16*s*. 6*d*.

In 1824 he records the delivery of his first bill for "surveys

and plans for the Corporation of Newcastle, per Jno. Clayton, Town Clerk, £16 16*s*." His reflections on arriving at manhood are a good example of the facility he possessed in expressing his thoughts, and show a correct appreciation of the work and duties of his future life. In 1828 he made sketches, which he afterwards etched, of the church and rectory of Whitfield, then held by his friend the Rev. Anthony Hedley, the learned divine and antiquary. His business increased very rapidly, and he prepared geological and mining plans of Hudgill Burn and Holyfield, and was much gratified to receive an order from Dr. Buckland, of Oxford, for six copies of the same. This proved the commencement of a friendship which continued till Dr. Buckland's death. He also prepared isometrical plans of Nentsberry, and surveyed and engraved plans of the Silver Band and other lead mines. In 1829 he engraved plans of Mexican mines for Mr. John Taylor, and he wrote a detailed account for the 'Newcastle Courant' of the burning of York Minster. This year he visited Mr. Crawhall, the manager of the great lead mines at Allenheads belonging to Mr. Beaumont, with which, fifteen years afterwards, he became so intimately connected. In 1830 he laid out a new road from Newcastle to Otterburn, which was considered equal, if not superior, to those made by the then well-known road-maker Macadam; and he was employed and consulted by Sir John Swinburn, of Capheaton, Sir Charles Monk, of Belsay Castle, Mr. Hodgson, Mr. Ord, and others; and this year he visited London for the first time. In 1832 he engraved a map of the "Colliery Districts," and read a Paper at the Natural History Society of Newcastle on "Isometrical Perspective;" took new offices in the Royal Arcade, and spent much time with Mr. Grainger in considering the contemplated improvements of Newcastle. The cholera was very prevalent in Newcastle during this year, and in connection with precautionary and preventive measures he made the acquaintance of Dr. D. B. Reid, and had frequent conferences with Mr. W. C. Trevelyan, of Wallington, Mr. John Clayton, the Town Clerk, and Mr. John Buddle, M. Inst. C.E. This year, also, in surveying the mines and taking levels for sections in the Forest of Dean, he designed and constructed a new levelling staff, which saved much time and secured greater accuracy than the staff then in use.

In 1833, on his thirtieth birthday, he was consulted by Mr. Buddle, on the instructions of Mr. Alexander Milne, of the Woods and Forests Department of the Government, on a proposed survey of the mines in the Forest of Dean, and had subsequent conferences with Lord Duncannon, which led to his preparing a report to that

department. It was "highly approved," and a few years afterwards he received his appointment as "Crown Commissioner." This year he was a witness before a committee of the House of Commons on the Derwent Road Bill. On the 7th of May, 1833, he was, on the proposal of Mr. Telford, the President, Mr. Turnbull, and Mr. Buddle, elected a Member of the Institution of Civil Engineers. His diary for this year contains a description of the riotous and disorderly conduct of the people at the parliamentary election for Leeds, and a suggestion that "if Members must be dependent for their election on the amount of money they can expend, it might be arranged to elect the man for whom, or in whose name, the greatest amount could be raised in any way or by any number of persons, and apply the money in reduction of the rates and taxes." In the same year he published "An Account of the Mining Districts of Alston Moor, Weardale, and Teesdale."

In 1834 his large treatise was issued on Isometrical Drawing, with thirty-four engravings on copper, which went through several editions. In this year he was engaged on several important cases of reference, in company with Mr. Buddle and Mr. Nicholas Wood. In 1835 his isometrical plans of Mr. Grainger's new buildings, and elevation of new streets in Newcastle, were published. About the same time appeared geological sections of lead mines in Alston and Teesdale, eight views of Fountains Abbey, an account and plans of Alston Moor and Weardale district, and plans and sections of a railway, or tramroad, from Blaydon to Spittall, which he had surveyed in connection with Mr. John Blackburn.

In 1836 he prepared plans for Mr. Grainger, which were afterwards published, for concentrating the termini of the Newcastle and Carlisle, the Great North of England, and the proposed Edinburgh railways. He records the cost of his journey from Newcastle to London as having amounted to £6 2*s.* 3*d.*, inclusive of £4 10*s.* for the coach fare, per the Highflyer, the time occupied being thirty-four and a half hours.

In April 1837 he gave evidence before the parliamentary committee on the London and Brighton railway, in favour of the bill. He records his cross-examination by Mr. Wood, afterwards Sir William Page Wood and now Lord Hatherley. This year he was also employed for the Great North of England railway, and was the guest of Dr. Buckland, at Oxford. In 1838 he records the opening, on June 18th, of the Newcastle and Carlisle railway, from Blaydon to Carlisle, a distance of 60 miles, and notes that the first train was run from end to end in 3 hours 43 minutes.

In 1838 he was appointed Commissioner for the Crown, in

company with Mr. Probyn for the Free Miners, and Mr. Buddle as umpire, under the "Forest of Dean Mining Act." This appointment was very gratifying to him, as it had not been sought, directly or indirectly. In this year he contributed to the Transactions of the Cornwall Polytechnic Society, a Paper on "An Easy Means of Recording the State of the Weather." To various sections of the British Association, which met this year at Newcastle, he sent six Papers, viz.: 1. "On Sections of the Mountain Limestone Formation in Alston Moor, exhibiting the general uniformity of the several beds." 2. "On the Construction of Geological Models." 3. "Description of an improved Levelling Stave for Subterranean as well as Surface Levelling." 4. "Description of Instruments to facilitate the drawing of objects in Isometrical Projection." 5. "On an improved method of Constructing large Tables, or Writing Cabinets, adapted to save much time, and secure the systematic arrangement of a great number and variety of Papers." 6. "Suggestions on the practicability and importance of preserving the National Mining Records." The suggestions contained in the last-named Paper led to the appointment of a committee of the Association, consisting of the Marquis of Northampton, Sir Charles Lemon, Mr. Buddle, and Mr. Sopwith, which succeeded in inducing the Government to take up the subject, and resulted in the establishment of the present Department for Mining Records. About this time he wrote a Paper, for the Geological Society, "On the Illustration of Geological Phenomena by means of Models."

In 1839 he wrote a Report on the Mineral Districts of the County of Clare, Ireland, and delivered lectures at Newcastle on "Astronomy," on "Glaciers in Great Britain," and on "Economic Geology." In this year he was again the guest of Dr. Buckland, at Oxford, and records his admiration of the beautiful collection of drawings by Mr. Ruskin. He conferred with Mr. Babbage on the celebrated Calculating Machine, the further progress of which was stopped for want of funds, although it was nearly completed, and £20,000 had been spent on its construction. His social intercourse and correspondence at this time included Sir Francis Chantrey, Sir Roderick Murchison, Professor John Philips, Bryan Donkin, Dr. Buckland, Babbage, Mary Somerville, Rendel, Cubitt, Robert Stephenson, Buddle, and most of the active minds then employed in nearly every department of science and engineering.

In 1840 he exhibited at the Institution of Civil Engineers a model of 36 square miles of the mining district of Gloucestershire, showing its geological formation. In the following year he directed the attention of the members to the geological sections

opened out by the railway cuttings, and other engineering works then in progress, and he afterwards induced the British Association to vote £200 for securing authentic records of such sections.

In June 1841 a Paper by him was read at the Institution of Civil Engineers, "On the Construction and Use of Geological Models in connection with Civil Engineering." In that communication he treated of the peculiar advantage of models over plans and sections for mining purposes; dealt with the materials for models, their mode of construction, the scales to be employed, and the objects to be represented; and spoke of the conviction they carried to the mind, as well as their general use for all purposes of civil engineering. For that Paper a Telford Medal was awarded to him; and the Council, in their Annual Report, alluded to the mutual advantages to be gained by the geologist and the civil engineer from a more intimate communion of their respective sciences, as brought under the notice of the Institution by Mr. Sopwith. In the same year he dedicated to Dr. Buckland a "Description of a series of Geological Models, illustrating the nature of stratification, valleys of denudation, succession of coal seams in the Newcastle coal field, the effects produced by faults or dislocations of the strata, intersection of mineral veins, &c." His "Account of the Museum of Economic Geology, and Mining Records Office" was printed in 1843. In the following year he published another Paper on "The National Importance of preserving Mining Records."

Mr. Sopwith was elected a Fellow of the Royal Society on the 5th June, 1845. He was much engaged in Belgium about this time with the late Mr. George Stephenson and Mr. (afterwards Sir) William Cubitt, and took an active part in the construction of the Sambre and Meuse railway. He was consulted also by the Belgian Government, and had interviews with the King of the Belgians on the framing of the laws applicable to the future development of railways in Belgium. About this time he was for a few years in partnership with his brother-in-law, Mr. Marcus Scott, and Mr. T. Macdougall Smith, M. Inst. C.E. He became a member of the Society of Arts in 1845; and in the Journal of that Society for Nov. 4th and 11th, 1853, will be found a Paper on "Practical Observations on Surveying and Levelling." In 1846, 1847, and 1848, he was a Member of the Council of the Institution of Civil Engineers, and during those years, as well as before and after, occasionally took part in the discussions at the weekly meetings of the Institution. In 1846 he published "Observations addressed to the Miners and other Workmen employed in Mr. Beaumont's Lead Mines in East

and West Allendale and Weardale." In this pamphlet he describes himself on the title page as a "Member of the Geological Society of France, Commissioner for the Crown under the Dean Forest Mining Act, and Chief Agent to Mr. Beaumont's Mines in Northumberland and Durham." In the same year, in conjunction with Mr. T. M. Smith, M. Inst. C.E., he issued "Reports on the Ironworks, Manufacturing Establishments, and Mineral Property at Couvin, in the District of the Sambre and Meuse, in Belgium." In 1853 he published a pamplet on "Education; its present state and future advancement, being the substance of a Lecture given in one of the new Schools recently erected by W. B. Beaumont, Esq., M.P., at Bywell, in Northumberland." In 1854, on the occasion of the Educational Exhibition held by the Society of Arts, Mr. Sopwith gave a lecture on "Models and Diagrams." In 1855, at the request of the Council of the Society of Arts, he gave an explanation of the mineral products at the east end of the Annexe at the Paris Exhibition. In the same year he delivered one of the evening discourses at the Royal Institution, 'On the Mining Districts of the North of England;" and a little later he delivered an address, in his capacity as President, to the members of the Tyneside Naturalist Field Club. In 1857 he presented to the Institution of Civil Engineers an "Account of the Steam Ferry over the River Nile, at Kaffre Azzyat," which came under his observation when he visited Egypt with the late Mr. Robert Stephenson, M.P. This year he printed a little volume, entitled, "Notes of a Visit to Egypt, *via* Paris, Lyons, Nismes, Marseilles, and Toulon." In this year the honorary degree of M.A. was conferred upon him by the Senate of the University of Durham. The Rev. Temple Chevalier, who presented him to the Senate on that occasion, adverted to his (Mr. Sopwith's) long connection with the University, and the frequent services he had rendered as examiner and steward. He commented on his efforts to advance practical education in the mining districts, to his services as Commissioner of the Town, and to what the Senate had deemed to be services rendered generally to society and science. In 1858 he was elected a Member of Council of the Society of Arts, which position he retained until 1863, and in subsequent years took part in the proceedings of that body, and acted on several occasions as Chairman at the ordinary meetings. The "Proceedings of the Geologists' Association" for 1859, contains a Paper by him "On the Lead Mines of England." In the inaugural address of Sir W. G. Armstrong, C.B., V.-P. Inst. C.E., as President of the thirty-third meeting of the British Association,

held at Newcastle-upon-Tyne in August and September 1863, occurs the following passage: "At the last meeting of the British Association in this town, the importance of establishing an office for mining records was brought under the notice of the Council by Mr. Sopwith, and measures were taken which resulted in the formation of the present Mining Records Office." At this meeting Mr. Sopwith was one of the secretaries of the geological section, and contributed a Paper on "A Section of the Strata from Hownes Gill to Cross Fell," and he also presented a joint report by himself and Mr. T. Richardson, "On the Local Manufacture of Lead, Copper, Zinc, Antimony, &c."

He kept regular meteorological observations at Allenheads and Bywell, which were transmitted to the Registrar-General, and were interesting mainly in consequence of the difference of elevation, which was no less than 1,273 feet, and of the meteorological conditions existing at Allenheads, which is surrounded by a large extent of high and damp moorland. He was for many years a Fellow of the Meteorological Society, and was President during the years 1859–61. He was a member of the Government Commission on the Use of Gun Cotton as a substitute for Gunpowder in Blasting, and was afterwards engaged with Prof. Abel in further experiments, the results of which were printed in a Parliamentary return.

During the twenty-six years from 1845 to 1871, when he was principal agent of Mr. Beaumont's lead mines in Northumberland and Durham, he was resident for the first twelve years almost constantly at Allenheads, in the midst of the two thousand workpeople, and their families, making a total population of about ten thousand. His love of order and punctuality caused many new arrangements to be introduced for the comfort of the workpeople and their families. Their houses were improved, and many new ones built with due regard to health and family comfort. Schools and libraries were established, and exhibitions occasionally held. The schools were open to all denominations alike, and the religious difficulty was removed by the reading of short selected passages from the Bible, to which none could object. The mode of teaching religious lessons, as carried out at these schools, was shown by him in evidence before a Parliamentary Committee, when he illustrated the various lessons a teacher might give from the 19th Psalm. The children were made to think, and every writing lesson was a useful piece of information; punctuality was constantly enforced, and a system which Mr. Sopwith called "drill arithmetic" was successfully carried out. Object lessons, freehand

and geometrical drawing, grammar, composition, geography, and, not least, the importance of punctuality, integrity, and good conduct in every relation of life, were sedulously enjoined, and constantly illustrated and enforced.

When resident at Allenheads he was visited by Michael Faraday, Robert Stephenson, Sir Roderick Murchison, William and Robert Chambers, Prof. Pillans, and many other literary and scientific men. His journal contains frequent allusions to the conversations and intercourse he had with the distinguished men of his time, and these are charming from the unaffected manner in which they are related, and interesting in many cases as chronicles of strong and vigorous expressions called forth by the incidents of an afternoon walk, or occurring in friendly conversation. His journals impress vividly on the reader his candour and honesty with regard to what he wrote, and how ready he was to treasure and profit by the intercourse he held with any distinguished guest; one in particular, Mary Somerville, writes of him in her book of 'Recollections:' "His conversation was highly interesting, and to him I was indebted for much information while writing on physical geography. Many years after, he and Mrs. Sopwith came to see me at Naples, which gave me much pleasure. He was unlike any other traveller I ever met with, so profound and original were his observations."

His love of drawing, and facility in sketching, enabled him to assist Mr. Hodgson in his 'History of Northumberland,' and Mr. Surtees in his 'History of Durham,' and secured him the friendship of these eminent local historians.

In 1870 he records in his Diary the following reflection: "During fifty years I have enjoyed a very large share of domestic comfort, of professional occupation, and, above all, of many most precious and esteemed sources of happiness in family affections and in most valued friendships. Wealth I have never coveted, nor splendour nor power; a fair competency has rewarded my exertions in business and in professional matters."

In March 1871, as previously arranged with Mr. Beaumont, he gave notice to the principal managers of the various departments at the W. B. lead mines of his intention to resign in June next, on the completion of twenty-six years service, and fifty years active duties in his profession. At a complimentary dinner, given to him on his retirement, a service of plate of the value of two hundred guineas, was presented to him by the workmen and agents of the W. B. lead mines, "as a testimonial of their respect and esteem

for his skill and integrity in the discharge of his duties during a period of twenty-six years; and also to mark their appreciation of his zealous efforts in promoting education, and other benevolent objects." Sixteen hundred and twenty-one persons subscribed to this testimonial, and it was accompanied by the following address:

"To Thomas Sopwith, Esq., M.A., F.R.S.

"We, the undersigned, as the representatives of the workmen employed in the extensive lead mining and smelting industries of Allendale and Weardale, on being apprised of your intention to retire from the chief agency of the W.B. lead mines and mills, at once unanimously resolved that we would endeavour in some form to show our very great esteem for you; and we now offer for your acceptance sundry articles in silver, in value two hundred guineas (towards which we have had the contributions of the various agents), and in the present address we wish briefly to indicate the sentiments which have impelled us to offer the gift to you.

"1st. As chief agent we have much to thank you for in the improvement of our position, such as the increase of monthly subsistence-money from 30*s.* to 40*s.*, the lessening of surface workmen's hours of labour one and a half hours per day, and your constant willingness to promote any plan that has had for its object the welfare of the workmen.

"2nd. As a philanthropist, in the libraries, news-rooms, benefit societies, improvement classes, &c., &c., and, above all, in the establishment of excellent schools (open to all sects), by means of which the workmen's children obtain the great boon of a sound and useful education at a trifling cost, we have abiding testimony of your energetic promotion of the social and intellectual welfare of the inhabitants of these dales; and we cannot forego this opportunity of expressing our gratitude to our honoured and distinguished employer, W. B. Beaumont, Esq., M.P., for so heartily joining in carrying out all those schemes, both by his munificent donations thereto, and by his well-known desire to further any plan that has for its object the improvement of his workmen and their families, in respect both to their religious, moral, and social interests, without distinction of sect or creed. The admirable working and flourishing condition of these institutions in the various localities testify to your ability in having them based on sound principles, and to the constant and cordial interest you have always taken in them. We would here express our belief that the

establishment of so many philanthropic institutions, your great thoughtfulness in recognising merit and helping its promotion to places of honour and respectability, and your constant advocacy of temperance and good habits, have had an immense effect in the diminution of vice and drunkenness, once so prevalent in these districts.

"3rd. As a scholar, we wish to express our appreciation of your talents and ability, and the pride we feel in knowing the eminent position you have worthily attained in the scientific and literary world.

"4th. In your private character, and that of your esteemed family, we have always had examples of kindness and geniality of disposition, which we cannot cease to remember with feelings of pleasure and endearment.

"It is with great regret that we think of your retirement from the active duties of your profession as the breaking of the close link which has existed between yourself and the many workmen over whom you have for upwards of a quarter of a century exercised so beneficial a supervision; but in this our parting interview with you to-day, we would most sincerely add that the wish of all of us is that you (with Mrs. Sopwith and your family) may be long spared in health and happiness; and as all the blessings you have bestowed have been highly appreciated, so we feel sure that you will meet with the reward promised to all who do such good."

Mr. Sopwith said, in acknowledging the presentation, that "when he came, twenty-six years ago, there was certainly not that amount of quiet comfort and respectability amongst the working classes generally that they now saw existing. . . . . The mines, which were supposed to have been nearly exhausted, and said by some when he first came to be nearly at their last end, had been wrought to considerable advantage, and had been the means of employment to large numbers of people. He believed that there were yet wide and untried fields, where enterprise might make its way and discover the means of occupation and of comfort for many years to come. One such district was in Weardale, and two or three in Allendale, and he trusted that the measures which had been taken on a large scale, more especially by the prosecution of the Blackett level, would produce for many generations that prosperity which had now for upwards of a century largely existed, and which had for three or four centuries existed, although upon a smaller scale. Having alluded to this

prospective view, he would briefly mention his deep obligations to those who had been associated with him in the management of that property. Any man who looked honestly into his own heart, and had the capability of discernment, must know very well that in the management of a large property he could not succeed unless ably assisted by all hands. This was especially the case in a property extending over more than 200 square miles, embracing a population in round numbers of from 10,000 to 12,000 people directly or indirectly interested in mining pursuits, and from 2,000 to 3,000 people actually employed therein. There had been many great operations during his agency, and he might say that he had looked forward to prospective benefit rather than to the circumstances of immediate produce and advantage. The mining operations had been satisfactory and steady, for, looking over the returns for the last twenty-five years, and taking averages each five years, he could not help observing the steady and regular return of produce. There was one thing more than any other to which he wished to advert, and he need scarcely tell them that that was how deeply affecting it was to his feelings to leave a district to which he was so much attached. He liked the district, he liked the people, and he was deeply grateful, as he was bound to be, for the attention, the willing obedience, the constant friendship, and cheerful assistance of all who had been associated with him. . . . He could gladly refer to one and all in terms of commendation. Alluding to the comparatively few accidents which had happened in connection with the works, it might be said that the average number of accidents was less than what usually occurs on the surface amongst a similar number of people. Mr. Sopwith referred to the subject of education, taking some small credit to himself for assisting in establishing schools which were an honour to the district. He considered that it was owing to the care taken in the training of the young that they had so much happiness and propriety of conduct in that district. It seemed almost impossible for the children to go wrong after they left schools where so much pains had been taken by their teachers. He next spoke of the good which had been achieved by Benefit Societies during the last twenty years, the advantages of which had attracted attention even beyond the particular sphere for which they were established. He begged to thank them in the warmest manner he possibly could for the kind sentiments of friendship they had expressed towards him. In thus thanking them let him also express his best wishes for their comfort, welfare, and prosperity in every way. They acted under an employer who would warmly

appreciate whatever was done in his service; and so long as this upright industry and correct feeling prevailed, all would be well. He trusted that the absence of these qualities would never be felt. . . . . He did not think there was in Great Britain, or he might say in Europe, if even in the world—an equal number of persons, on an equal area of ground, such as in this and the adjacent mining districts, where there was so little poverty, where so little distress was to be met with, or where a greater amount of civility of manners and propriety of conduct would be met with than in those mining dales. He spoke generally of Alston Moor, Teesdale, and Weardale, as well as Allendale. From his experience of these places, he believed that there was a greater number of persons well-clad, well-behaved, well-intentioned, honest and contented, than they could find in any equal area of any other part of the world containing an equal number of people. (Applause.) He felt great pleasure in addressing them on that occasion, more especially in addressing to them sentiments which it would be his greatest happiness to know had their concurrence and approval."

Mr. Sopwith entered on his career when the engineering profession was, it may be said, in its infancy. The Stockton and Darlington railway was opened when he was twenty-two, and the Liverpool and Manchester before he had attained his twenty-seventh year. It was not, however, railways to which he specially devoted his attention, as from the first he laid out a course for himself which eventually placed him as one of the foremost of engineers in metalliferous mining. Great industry, exactness in details, clearness of expression, the observance of method to a fault, and conscientiousness in all his transactions, were characteristic of Mr. Sopwith. He was a fluent speaker and a ready and precise writer, as is proved by the journals already referred to, which contain interesting descriptions of places and people, interspersed with amusing pen-and-ink sketches which would do credit to a professional artist. At a very early period Mr. Sopwith evinced a great appreciation of organ music, and this faculty was cultivated and developed, and formed a constant source of pleasure and relaxation in after life.

Up to within a few months of his death, which occurred at his residence in London on the 16th January, 1879, Mr. Sopwith enjoyed excellent health. He was fond of travelling, and visited many places on the continent, and few localities of interest in the British isles were unknown to him. With his natural flow of high spirits, conversational powers, and well-stored and retentive

memory, he was a genial companion and a good friend, and will be long remembered by those whose advantage it was to have the pleasure of his acquaintance.

Amongst the pupils who studied under Mr. Sopwith may be named Sir George Elliot, Bart., M.P; Mr. Joseph Dickinson, Her Majesty's principal Inspector of Coal-mines, and Mr. Thomas John Bewick, M. Inst. C.E., the latter of whom was upwards of thirty years in close connection with him, and ably assisted him in the introduction of Sir William Armstrong's improved hydraulic machinery into Mr. Beaumont's extensive mining districts and other great mechanical and social improvements.

Mr. Sopwith was elected a Member of the Institution on the 1st of May, 1833, and there are now only twelve members on the list who were elected at an earlier date. The last occasion on which he took an active part in its proceedings, was so late as the 5th of November, 1878, and many who were present on that occasion will testify to the admirable effect of his address then, clearly expressed and fluently delivered, in a conciliatory spirit well adapted to the object in view. He concluded by expressing his sense of the high character and honourable standing attained by the Institution, and said that at the close of his life, which in the nature of things could not be far distant, he looked forward with pride to a record being made over his grave that Thomas Sopwith had been a "Member" of the Institution.

SIR WILLIAM FOTHERGILL-COOKE was born in 1806, near Ealing, Middlesex. He commenced his professional career in the Indian army. In 1835–36, being on furlough from his regiment, his leisure time was devoted to the study of medicine and anatomy, both at Paris and at Heidelberg. Whilst engaged at the latter place in modelling dissections for the museum of his father (then Professor of Medicine and Anatomy in the rising university of Durham), Mr. Müncke, Professor of Natural Philosophy, showed him a model which Baron Schelling had previously exhibited at Bonn. By this instrument, two movements of a magnetic needle at a distance were rendered visible by an electric current. The idea of electrical communication immediately took possession of Mr. Fothergill-Cooke's mind, and a deep conviction of the practicability and incalculable utility of an electric telegraph. Relinquishing other pursuits, he resigned his commission, and devoted himself at once

to the realisation of this conception. In April 1836 he came to England, to perfect his plans and instruments; and during the summer of that year he prepared a pamphlet (since widely circulated) entitled, "Plans for establishing on the most extensive scale, and at trifling expense, a rapid telegraphic communication, for political, commercial, and private purposes, especially in connection with the extended lines of railway now in progress between the principal cities of the kingdom, by electro-magnetism." In reference to the above it was stated in the 'Scientific Review' for 1868, page 198, that "The timely origination of the electric telegraph (coincident with the railway era) by Mr. Cooke, in March 1836, his clear conception and foresight of the vast results that would spring from it, his accurately-defined system of working it, were all graphically delineated in his pamphlet, written in June 1836, which is now regarded as an accurate and ample prophecy of that great invention, since realised by himself." This pamphlet led to negotiations with the Liverpool and Manchester Railway Company, and to results which are stated as follows, in the authoritative award of Sir Isambard Brunel and Professor Daniell: "In February 1837, while engaged in completing a set of instruments for an intended experimental application of his telegraph to a tunnel on the Liverpool and Manchester railway, he (Mr. Cooke) became acquainted, through the introduction of Dr. Roget, with Professor Wheatstone, who had for several years given much attention to the subject of transmitting intelligence by electricity, and had made several discoveries of the highest importance connected with this subject. . . . . In May 1837, Messrs. Cooke and Wheatstone took out a joint English patent, on a footing of equality, for their existing inventions. The terms of their partnership, which were more exactly defined and confirmed, in November 1837, by a partnership deed, vested in Mr. Cooke, as the originator of the undertaking, the exclusive management of the invention, in Great Britain, Ireland, and the Colonies, with the exclusive engineering department." Immediately after the patent was sealed, Mr. Cooke induced the London and Birmingham Railway Company, under the auspices of Mr. Glyn, their chairman, and of the late Mr. Robert Stephenson, to try extensive experiments with 20 miles of wire, between Euston Square and Camden Town. These experiments were entirely successful, and Mr. Cooke shortly afterwards laid down a telegraph between Paddington and Slough. The next line of importance was adapted, under the auspices of the late Mr. Bidder, to the complex arrangements of the Blackwall railway, which was then worked by a rope and fixed engines. He also published, in 1842, a work entitled, "Telegraphic Railways, or the

Single Way,"[1] which was translated into German, French, and Italian. The system explained in this work was adopted by several of the leading engineers, on the Yarmouth and Norwich, the Northampton and Peterborough, and many other single lines of railways. These severe trials of the telegraph speedily brought it into general request, and it became known as the "block system."

On the 10th April, 1843, Sir Charles Wheatstone's royalty on licenses was, by deed of agreement, converted into a mileage charge to be paid to him by his partner. Mr. Cooke, thus left at liberty to deal with the invention in whatever way seemed most likely to extend its use, sold an exclusive right of employing the electric telegraph in Kent to the South Eastern Railway Company for £10,000. He had previously invited the board of the South Western Railway Company to join him in establishing a telegraph to Portsmouth for the Government, who offered an annual subsidy of £1,500. In these contracts Mr. Cooke reserved the right of fixing wires for commercial purposes on the lines of the companies; and this system gradually established itself on all the important lines of Great Britain, and still remains in force.

The demand for electric telegraphs over the railway system of Great Britain soon exceeded the power of an individual to supply. The great enterprise had been started with a few hundred pounds. On the 30th September, 1845, Mr. Cooke had orders under execution, or soon to be commenced, for about 800 miles, which showed an estimated profit of £56,366. He entered into negotiations for the sale of the patents with the founders of the Electric Telegraph Company, offering to execute these lines himself, and to take his estimated profit as part payment for the patents. The company, however, preferred to take the contracts, and included them in the purchase of the patents, as well as a sum of £30,000 which was paid to Professor Wheatstone in cash, for the purchase of his royalties. The late Mr. John Lewis Ricardo, M.P., his uncle Mr. Sampson Ricardo, Mr. G. P. Bidder, and two other gentlemen, formed with Mr. Cooke the nucleus of the first electric telegraph company. An Act of Parliament, obtained in 1846, gave the company most important privileges, and (what was rare in those days) limited liability. Under Mr. Lewis Ricardo's able leadership, during ten years, the electric telegraph became speedily a national institution. Its great success brought forth many rivals, free from the difficulties of a first undertaking to contend with. The mother company, not attempting to maintain a monopoly, but trusting to

[1] A copy of this treatise is preserved in the Library of the Institution.—SEC. INST. C.E.

its established position, its extensive network of telegraphs, and its exclusive agreements with the railway systems, whose friendly co-operation had been secured by affording them every facility for their traffic, entered at once into liberal arrangements with their rivals for a general working scheme, and thus avoided a competition which might have been ruinous to all. When the Central Telegraph Company first began business, in 1847, the daily receipts amounted to a few pounds. At the close of 1869 they exceeded £1,000 a day, paid over the counter.

During the gradual establishment of the electric telegraph Mr. Cooke devoted much attention to other important subjects. For some years, as chairman of a company, he aided the late Mr. Wicksteed, M. Inst. C.E., in reducing to practice his system of purifying the sewage of towns, by establishing extensive works at Leicester. The whole sewage of Leicester and the neighbouring district was operated upon with perfect success; the impurities, deposited at the bottom of extensive tanks, were skilfully removed from under the water, and solidified into inodorous brick-shaped cakes for manure, the overflow passing off in a clear stream to the river. The health of the town was vastly improved, and the low-lying districts, previously the focus of fever and its concomitant evils, were rendered salubrious. Unfortunately the dried deposit had but little manural value, and the works, on which over £40,000 had been expended, were ultimately made over to the town.

In 1845 Mr. Cooke, then a member of the Council, and a Vice-President of the Society of Arts (having taken an active part in the resuscitation of the Society), prepared an elaborate sketch of a plan for a universal exhibition of the products of industry of all nations, to be carried out under the supervision of the society. The documents connected with this subject are in the possession of the Society, and from the 'Journal of the Society of Arts' for January 15, 1869, page 128, the following is extracted:

"EXHIBITION OF BRITISH INDUSTRY, ETC., PROPOSED.

"During Mr. Whishaw's secretaryship, the rules excluding patents from rewards were abolished, and the first attempt at establishing an exhibition was suggested, and in 1844–45 a circular was issued, headed, 'Proposed Exhibition of the Products of British Industry,' in which it was set forth that 'The exhibitions of national industry, which attract so much attention on the Continent, have suggested to some members of the Society of Arts and to some distinguished manufacturers the propriety of establishing

something of the kind in this country.' Special subscriptions in aid of the proposition were received, and the originator of the plan, though then unknown, was Mr. Fothergill Cooke, the inventor of the electric telegraph. Exhibitions, as then proposed, were to be of two kinds—industrial and art. The former were to have been limited to British manufacturers, and in the latter case the artists contributing pictures to the proposed exhibition were, by ballot, to act as judges of their own works, and were to receive pecuniary rewards, towards which, however, each artist was to contribute £1 1*s*., to form, with other moneys, a common prize fund. It is scarcely necessary to add, that neither proposition, as originally put forward, was ever carried out."

This proposition led, in 1851, to the first Great Exhibition. Mr. Cooke's early services on this occasion occupy the second paragraph of an official document, drawn up and published by order of the late Prince Consort, President of the Society of Arts, under whose enlightened auspices the great scheme was perfected and realised.

Through his friendship with the late Mr. I. K. Brunel, Mr. Cooke became at an early period connected with the Great Eastern steamship, and was for some years, after its first return from America, a director of the company, and took an active part in the restoration of the vessel before it conveyed the troops to Canada during the American war.

Mr. Cooke's energies and inventive faculties were, after this, for some years devoted to the perfecting (in conjunction with Mr. George Hunter, of Arbroath) of an entire system of machinery for working stone, slate, and other minerals, beginning at the quarry, and carrying out every operation systematically up to the most ornamental work for building purposes. Parts of this system are now in operation, though his declining health and other circumstances compelled him to withdraw, some years back, from active participation in the undertaking, and, finally, to retire from all business, and to give his brain and body the rest which they so much needed, and had well earned.

He was elected an Associate of the Institution of Civil Engineers in May 1867, when his qualifications were stated to be "the prominent part he has taken, since the year 1837, in the scientific and practical applications of the electric telegraph to commercial purposes, and to the working of railways."

On the 19th November, 1867, the fourth Royal Albert Gold Medal of the Society of Arts was presented to Mr. Cooke, in recognition of his services in establishing the first electric telegraph, a duplicate being voted at the same time to Sir Charles

Wheatstone. The annual presentation of one of these medals, "for distinguished services beneficial to all civilised nations, and open to all nationalities," was decreed in memory of the late Prince-President of the Society. The first medal was awarded to Sir Rowland Hill, K.C.B., and the third to Dr. Michael Faraday, two of the greatest benefactors to modern civilisation.

On the 11th October, 1869, Her Majesty was pleased to confer on Mr. Cooke the honour of knighthood, "for his great and special services in connection with the practical introduction of the electric telegraph." Sir William Fothergill-Cooke died at Farnham, Surrey, on the 25th June, 1879, aged 73.

Sir William Fothergill-Cooke had a commanding appearance, a tall, well-proportioned, active figure, with an intellectual head, and a bright eye. In earlier life he was capable of great bodily exertion—a good rider, a keen sportsman, and noted for feats of strength and agility. His leading characteristic was perhaps the indomitable energy and perseverance with which he threw himself into, and thoroughly worked out, whatever he undertook, and which for the time would absorb his whole interest. This would apply to a puzzle, a trick at cards, or a game of chess, as well as to the more important studies and inventions which successively engrossed his attention. On such occasions he would disregard the flight of time, and through life he was late in retiring to rest. His motto was "Ne tentes, aut perfice," and he consistently acted up to it. He introduced admirable order into the accounts of the various enterprises under his management or direction, and also into those of his own estate when he held a large property in Hampshire, where he devoted considerable attention to draining and scientific farming. At this time of his prosperity he was a liberal host and landlord, much more considerate for the interests and welfare of others than mindful of his own expenditure. He had a great taste for astronomy, and ever strove to interest his own family and near friends in the study, as affording a field for infinite and illimitable research into the wonders of creation. He found great enjoyment in botany, and made one of the first collections of orchids in this country. He was fond of poetry, apart from rhyme, and wrote several poems, one of which, entitled "Memories of the Past," recounting adventures in India, he dedicated to his eldest daughter and printed for private circulation. It contains a very correct abstract of the mythology and religions of the East. Though disposed to take the lead in conversation, for which his general knowledge, retentive memory, and lively imagination well qualified him, he always weighed carefully whatever was said in rejoinder,

and would take up an apparently commonplace remark, and clothe it with a force of meaning and originality beyond its compass. This especially applied to his intercourse with children and young persons, by whom he was much beloved. Though of a quick and sensitive nature, his generous disposition led him to give his affections strongly and abidingly where they were responded to and appreciated.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Proceedings of the German Cement Makers' Union, at Berlin, on February 3, 4, and 5, 1879.

(Notizblatt des Deutschen Vereins für Fabrikatur von Ziegeln, Tohnwaaren, Kalk und Cement, 1879.)

It was stated that there are about forty cement manufactories in Germany, employing about eight thousand hands, and which turned out in the year 1878 about 2,625,000 barrels.

With reference to the influence of sulphates upon the time of setting, and the strength, of Portland cement, carefully prepared tables were submitted, to show the effect produced by an addition of from ½ to 5 per cent. of the following sulphates: potassa, soda, magnesia, alumina, ammonia, lime, iron, copper, zinc, and also alum. The results were somewhat conflicting. In several cases the addition of a smaller or a greater quantity of the same substance retarded or accelerated the setting. Thus the addition of 5 per cent. of sulphate of zinc shortened the time of setting two minutes, whilst the addition of 2 per cent. lengthened it one hour. The strength at twenty-eight days was, generally speaking, increased. An interesting table is given, which proves that the coarser particles in cement have some adhesive power, and that they do not play the part of sand only; but that the greater the proportion of particles that will pass a sieve with nine hundred meshes per square centimètre (= 0·155 square inch) in any cement the stronger it is, when mixed with 3 of sand.

Dr. Goslich referred to some experiments made by him to ascertain what volume of mortar could be obtained by the use of different cements, and sands of different degrees of coarseness, and from them concluded that the addition of the requisite water does not increase the bulk, that the quality of the cement does not affect the bulk of the mortar produced, and that the coarser the sand the less the resulting volume of mortar. Sand of three different degrees of fineness was used, and the weights per litre were found to be practically the same. The first was prepared by sieves with twenty and sixty, the second by those with sixty and one hundred and twenty, and the third by those with one hundred and twenty and two hundred and fifty-six meshes per square centimètre. Dr. Schumann, after experimenting in a similar direction, concludes that the bulk of a mortar in litres is obtained by dividing the weight of its components in kilos by their respective specific

gravities, and by adding the resulting figures. Amongst others, he gives the specific gravity of Portland cement as 3·13, and of coarse sand from the pit as 2·66.

With reference to new uses for Portland cement, it was mentioned that it was suitable for making sleepers and tiles.

Upon the influence of an admixture of lime with Portland cement, it was remarked, that although it was found that mortar composed of cement and sand only was perfectly sufficient for many purposes, yet it was difficult to work on account of its being very short, and also it did not adhere well to stone. Experiments were therefore made with mortars composed of Portland cement, lime, and sand, and their tensile and compressive strengths were carefully noted. From the results, which have been tabulated, it may be concluded that a proportion of 1 of cement to ¼ of dry hydrate of lime (= ½ milk of lime) will give the highest tensile strength, which is equal to an increase of about one-fifth due to the presence of the lime. The addition of lime would appear also to produce an increasing compressive strength, but the experiments recorded do not extend beyond a mixture of 1 and 1. In ordinary cement the compressive value is about ten times the tensile strength. In cement-lime mortar, with a large admixture of sand, it is twenty to thirty times its tensile strength. The addition of lime also makes the mortar much denser. A table is given which shows that the adhesion of the mortar to stone is greatly improved by the presence in it of lime.

Experiments without success had been made with kilns for burning Portland cement, made like cupola and blast furnaces. The material in both cases was either over or under burnt. It was mentioned that slurry might be dried in properly-constructed frames or trucks, which could be lowered into the kilns, and withdrawn through doors in the sides. Delbrück had experimented with twelve kilns in connection, the fire passing from one to another through flues, but he found that no economy of fuel was obtained. It had also been proposed to burn kilns in connection, the fire working upwards in one and downwards in the next. A kiln for burning cement by means of gas is being built in Poland. There is no difficulty in burning lime in ring kilns fired with gas. The lime produced is free from ashes, &c., and the saving of fuel, as compared with ordinary firing, amounted in one case to 20 per cent. V. DE M.

Experiments on the Strength of Different Thicknesses of Mortar Joints. By Lieut. E. W. CRESWELL, R.E.

(Professional Papers on Indian Engineering, Roorkee, viii., p. 21.)

The experimental bars of brickwork tested for transverse strength were 15 feet in length, by 2 feet 6 inches square. The foundations were built the whole length of the bar, the end portions of 2 feet

6 inches being laid in mortar, and the central portion of 10 feet being laid in mud to facilitate its removal before the test loads were applied. The thicknesses of joint tested were $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ of an inch.

The bricks were sand-moulded, kiln burnt, and were carefully gauged and sorted, so that the external dimensions of the bars might be the same with the different thicknesses of joint. The mortar consisted of 2 parts of steam-ground coal-burnt kunkur lime to 1 of sand.

Fifty bars were constructed in all, ten being built with joints of each of the above thicknesses; they were completed in August 1877, and the central portion of the foundation was removed in May and June 1878, leaving the bars supported for a length of 2 feet 6 inches at the ends.

To break the bars two stone slabs, 6 inches square and 2 feet 6 inches in length, were placed transversely, 1 foot apart, on the upper side of the brickwork, at equal distances from the centre, and on these rails were laid successively until the breaking load was reached.

The average breaking load of ten specimens of each thickness of joint is given below, exclusive of the weight of the brickwork; also (1), maximum, minimum, and mean values of the modulus of rupture in lbs. per square inch, exclusive of the weight of the brickwork; and (2), inclusive:

Thickness of joint . .	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	
The average breaking weight in lbs. . .	15,501	17,439	18,186	11,701	11,022	Exclusive of weight of bar.
Modulus of rupture Maximum	215	254	235	179	148	Do. do.
Modulus of rupture Minimum	140	151	182	93	93	
Modulus of rupture Mean .	176	198	206	133	125	
Modulus of rupture Maximum	240	279	261	205	174	Inclusive of weight of bar.
Modulus of rupture Minimum	167	177	208	119	119	
Modulus of rupture Mean .	201	223	232	158	150	

A. T. A.

Note on a Method of Covering Terraces.

By SEVERINO CASANA.

(Atti della Società degli Ingegneri e degli Industriali di Torino, an. 12, p. 63.)

The construction of the terraces, which form so marked a feature of Italian building, involves difficulties more serious than any other detail of civil architecture in Italy. The change of temperature from summer to winter, and the succession of hard frost to heavy

rain, are so trying, that few modes of covering have hitherto been found altogether satisfactory.

Signor Casana, having observed a special mode of covering terraces employed at St. Moritz, in the Upper Engadine, in 1874, has introduced the plan, with some slight modifications, successfully at Turin.

The method recommended is as follows: The terrace is covered with inch planking, which the diagram represents as ploughed and tongued. The brackets which are to support the gutters are built-in on the edge of the terrace. A thin layer of sand is spread over the planking, and this is covered with a species of water-proofed *papier mâché*, known by the name of *cartone bitumato*. This is covered in its turn with a thin coating of sand, and then with 3 inches of clay.

Signor Casana gives a minute description, illustrated by a diagram, of the details of this method of covering. His mode of making a substitute for the *cartone bitumato* deserves notice. He makes use of the stout brown paper which is made in rolls of great length. This he spreads over the sand, and then covers, in successive strips, with hot bitumen, spread out thinly by a broom. The bitumen is covered by another layer of paper, and this by another layer of bitumen, taking care to make the joints overlap. This is done five times.

F. R. C.

Long-Span Railway and Road Bridge between New York and Long Island. By HR. BARKHAUSEN.

(Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover, vol. xxv., p. 221.)

This is a review of the ten designs recently sent in for a long-span railway and road bridge across the East river (by way of Blackwell Island) between New York and Brooklyn. Although the East River bridge is still unfinished, the demands for some better connection between New York and its suburb are growing so fast that a company has been formed for the construction of a second and heavier bridge, to cross the river where, by its division into two channels by Blackwell Island, the necessary span would not be nearly so great as that of Roebling's bridge. Ten designs were sent in for this new bridge, for which the conditions laid down were, that it should have a long span of 734 feet, and a shorter one (over the other channel) of 618 feet, and a clear height above the river of about 130 feet. Herr Barkhausen's article gives first the various conditions as to approaches, allowable stress in materials, and so forth, followed by a short criticism of each of the ten systems proposed, all of which are illustrated, at least so far as the design for the long span goes.

Design 1 (L. W. Wright) is an excessively flat lattice arch,

combined with a lattice girder. No. 2 (G. A. Karwiese) is an iron arch (not fulfilling conditions as to headway), with braced spandrils. No. 3 (W. T. Morris, Cincinnati Bridge Building Co.), is essentially a suspension bridge, stiffened by making the cable into two fish-bellied girders, and also by using braced suspension rods. Design No. 4 (A. Lucius) is a compound lattice girder of the Pratt type (braces alternately vertical and diagonal), and of a depth equal to one-seventh of the span, the platform stiffened by seven smaller girders of the same type. No. 5 (W. S. Pope, Detroit Bridge Building Co.), is of the Roebling type, a suspension bridge, stiffened by an auxiliary girder along its whole length, stayed by cables direct to the top of the towers. No. 6 (E. W. Serrell and Sons) is of similar general type, with lighter auxiliary girder. No. 7 (H. Flad and Co.), has a double cantilever, supported by cables from the top of the towers at each pier, the two middle cantilevers being connected by a lattice girder. No. 8 (Clarke, Reeves, and Co., Phœnixville Co.), is practically a hinged arch, consisting of two fish-bellied lattice girders, from which the roadway is hung. The thrust on the towers is taken by two similar but much smaller girders, virtually forming a continuation of the arch from the piers on each side down to the ground. No. 9 (C. Macdonald, Delaware Bridge Building Co.), is in principle like No. 7—cantilevers connected by a lattice girder —but the arrangement is differently carried out. No. 10 (C. O. Brown) is also of the same type.

Of the three engineers appointed to judge the designs, two placed No. 8 first, and one second; one placed No. 9 first, and two second: two placed No. 7 third, and one No. 6.

A. B. W. K.

Long-Span Stiffened Suspension Bridge over the Monongahela River at Pittsburgh. By J. SEEFEHLNER.

(Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover, vol. xxv., p. 69.)

The Author gives engravings and a description of the bridge over the Monongahela river which was opened in March 1877, and of which a model was exhibited at Paris last year. He gives also notes as to the conditions under which the bridge was designed, stresses allowed in the material, the mode of erection, the weight and quantities of material used, and a summary of the cost, &c. The principal opening of the bridge has a clear width of 800 feet; its height above low water being about 80 feet. It is a suspension bridge, with each half of the chain virtually converted into the lower boom of a lattice girder, in order to attain the necessary stiffness. The bridge is made for a double line of tramway, with footways on each side.

A. B. W. K.

Iron Bridges on the Lower Austrian South-Western Railways (Köstlin-Battig System.) By J. KOHN.

(Allgemeine Bauzeitung, 1879, p. 17.)

The Köstlin-Battig system of bridge construction has been used to a considerable extent in Austria, and is much thought of by some of the chief Austrian authorities on the subject; on the railways named above, in particular, it has been used for all spans of more than 20 mètres (65·7 feet). The girders of this type of bridge are large bayed lattice, with vertical struts and diagonal ties; they have the lower boom horizontal throughout, and the upper boom horizontal through the centre bay, or some such small distance, and then sloped uniformly downwards towards each end, the depth over the abutments being about four-sevenths of that at the centre. This girder, therefore, approximates roughly to the parabolic girder, but with no curvature in any part of the boom. The middle bays are counterbraced as usual.

Two bridges of this type are described by Herr Kohn, the one a road bridge over the little Erlaf river at Wieselburg; the other a railway bridge over the great Erlaf river. The former is of two spans, each 93·5 feet clear, and 22·6 feet wide between the centres of the girders; the latter has two spans of 77·9 feet, and one of 78·3 feet in clear, and 15·3 feet wide between the centres of the girders. The Author gives details of the assumed intensity of loads and stresses, and the principal calculations used in proportioning the bridges. He gives also engravings of each bridge, showing all their principal details.

The whole weight of ironwork in the road bridge—which was constructed by Baumann and Steiger, of Simmering (Vienna)—was 70·3 tons, including 1·84 ton for the bed plates and roller bearings. This amounts to 7·3 cwt. per foot run. The whole weight of the ironwork in the railway bridge (which is for a single line of rails), which was constructed by the "Steierische Eisen-Industrie-Gesellschaft" of Zeltweg, in Obersteiermark, was 67·5 tons, including 2·75 tons of bearings as above. This amounts to 5·53 cwt. per foot run.

A. B. W. K.

On the Influence of the Length of Bearings on the Stability of the Longitudinal Beams of Bridges. By EDMONDO DUBOSC.

(Atti della Società degli Ingegneri e degli Industriali di Torino, an. 12, p. 38.)

Having occasion to examine the designs for a foot bridge, supported by two connected girders, it occurred to Signor Dubosc to make a comparative calculation of the resistance of the girders, taking no notice, in one set of figures, of the length of the bearings,

and specially calculating for that length in the other case. The beams of the bridge were joined over a pier, of which the bearing surface bore the relation to the theoretic lengths of the two beams of $\frac{1}{8}$ and $\frac{1}{10}$; and the bearings on the abutments were of the proportions of $\frac{1}{2\,3}$ and $\frac{1}{2\,6}$ of the same width. Signor Dubosc found that by the second mode of calculation an economy was effected, as compared to the first, of 13½ per cent. on the width, and 10½ per cent. on the depth required for the beams.

In the ordinary calculations for the longitudinal supports of iron bridges, it is the custom, according to the formulæ in use in Italy (which will be found in Signor G. Curioni's work on Construction[1]), to take no notice of the length of the bearings in the direction of the axis of the bridge, the bearing surface being supposed to be represented by lines at right angles to the axis. These lines are taken as being in the centre of an intermediate support, and at the end of the beams on the abutments.

The calculation may be made with equal exactitude if account is taken of the length of the bearing surfaces. Omitting the consideration of the permanent weight, and supposing the moving weight to be distributed over the whole of the beams, the line to be drawn will coincide with the right edge of the surface of the pier when the weight is on the right, and with the left edge when it is on the left of that support. As to the ends, with regard to that which is fixed, the line of support must be taken to coincide with the edge of the abutment; and with regard to that which is movable, this line will coincide with the edge of the abutment, or with the end of the beam, according to the position of the moving weight.

Considering now the permanent weight, it will be found that each edge of the pier and of the abutments becomes a line of bearing, so that instead of n divisions of the length, it will become $2\,n-1$. It is, of course, assumed that each point of support bears its proper weight.

Bearing in mind these observations, the calculation of the moments of inflection, and of the breaking force, are made as by the ordinary rule, a little more trouble being involved by the double calculation of the permanent and of the moving weights, the former being represented by a straight line, and the latter by the parameter of a parabola.

In the case detailed by Signor Dubosc, the bridge was 3·28 feet wide, the platform resting immediately on the top tables of two longitudinal bearers, of section in the form of a symmetric double T, with reticulated sides, 20 inches deep. The piers supporting the ends of the girders were 64 inches wide (in the direction of the sides of the bridge). The longitudinals rested for the distance of 24 inches each on the abutments; the clear spans of the two bearings were respectively 36·6 feet and 46·2 feet. Taking the weight of the bridge itself at 160 kilogrammes per lineal mètre, and the

[1] "Costruzioni civili, stradali, ed idrauliche," per G. Curioni.

moving weight at 400 kilogrammes, on each lineal mètre of the longitudinal rested a permanent weight of 80 kilogrammes, and a moving weight of 200 might come. Signor Dubosc then presents the two calculations, both for the fixed and for the moving weights, in parallel columns, and finds as an ultimate result the comparative weights of the metal resisting inflection to be as 65,850 by the new method, and as 56,850 by the old, giving an economy of 13½ per cent., which is shown thus to be attainable in the design, as far as resistance to inflection is concerned. The resulting numbers in the calculation as to breaking force are 861·5 and 959·5, showing an economy of 10½ per cent.

The proportion of 1 to 10, which, in the preceding example, obtains between the width of the pier and the length of the girder, is perhaps higher than is often to be met with in practice. It is due to the nature of the watercourse which has to be passed, which is that of a torrent, impetuous when in flood; and the pier was designed with the view of resisting the shock of the current, and of the bodies, sometimes of considerable size, which it bears down. In a tranquil river the dimensions of the pier, as deduced from the weight which it would have to support, would probably give a width considerably less than $\frac{1}{10}$ the span. But whenever the proportion is not less than $\frac{1}{12}$ or $\frac{1}{13}$, it is desirable, in Signor Dubosc's opinion, to take into account the length of the bearings. The Paper is accompanied by three large diagrams, in which the moments of inflection and of breaking weights are graphically developed.

F. R. C.

The influence of Gradients on the Cost Price of Conveyance by Railways. By M. MENCHE DE LOISNE.

(Annales des Ponts et Chaussées, 5th series, vol. xvii., p. 283.)

The Author was led to the investigation of this subject for the purpose of determining whether a new line of communication between the east and south-west of France could be advantageously constructed, and also with reference to the route of exchange of traffic between the northern and eastern companies.

The average cost of conveyance is obtained fairly enough, if taken over a considerable distance and for a long period, by dividing the total cost of working by the actual tonnage per mile. This average is divisible into two parts—one dependent on, and the other independent of, the gradient. The expenses depending on the gradient relate to the brakes, the traction, and the wear of the road, and may be considered as proportional to the resistance which would be experienced in drawing a ton of goods at the same speed on different inclines.

The Author enters into an analysis of the returns of the original line of the Northern Company for 1877, on which the steepest gradient is 1 in 200, from which it appears that the cost of con-

veyance on that line per ton per mile is 0·394*d.*, of which 0·22*d.* represents the portion independent of gradient, and 0·174*d.* the portion influenced by it. From these data the Author has compiled a table showing the relative costs for the several gradients on the whole of the Company's lines, of which the total costs per ton per mile are as follows: for gradients from zero to 1 in 200, 0·394*d.*; for gradients of 1 in 140, 0·427*d.*; for gradients of 1 in 110, 0·449*d.*; for gradients of 1 in 90, 0·475*d.*; for gradients of 1 in 77, 0·516*d.*; for gradients of 1 in 66, 0·571*d.*; and for gradients of 1 in 59, 0·653*d.* He has also prepared a table giving the distances that a ton load could be drawn on a gradient between level and 1 in 200, at the same cost as along a mile on the several gradients given above, which are obtained, in miles, by dividing each of the above money values successively by the first.

In comparing the cost of conveyance by rail and by road, it appears that an increase in gradient affects the cost much more on railways than on roads.

The Author points out that it would be impossible, in his investigation, to separate passenger from goods traffic, as they are not given separately in the returns, but that it does not materially affect the result.

The cost per train mile varies considerably on different lines, being, in 1877, only 2*s.* 8*d.* on the old Orleans line, the average journey of a ton being 110 miles; whilst on the old Southern railway it amounted to 4*s.* 2*d.*, the average journey of a ton being 75 miles. However, though the costs are different, the proportions on the several gradients are nearly the same on the various lines.

The results arrived at, when applied to the case the Author had to determine, have led to the choice of the line from Cateau to Laon in preference to a line from Cateau to Saint-Erme.

L. V. H.

The Works of the Hanoverian State Railway at Leinhausen, near Hanover. By Hr. SCHWERING.

(Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover, vol. xxv., pp. 23–45 and 167–199.)

The Hanoverian State railway has hitherto had its repairing shops close to the passenger-station at Hanover, but of late years the traffic of every kind has grown so enormously that it was no longer possible to get room on the old site for the extension which had become necessary. In order to obtain this room, as well as space for the still greater extension to be expected in the future, it has been necessary to go to a distance of about 1¼ mile north of the present station, to a new site at Leinhausen. The ground purchased for the works is about 109 acres, of which,

however, only 89 acres have been enclosed for the present. In addition to this, about 52 acres adjoining the works have been purchased for the erection of workmen's houses, of which the plan provides two hundred, each house suitable for two families. As yet only forty of these houses have been built.

Herr Schwering gives a detailed description, illustrated by numerous plates, of the works themselves, both as to general arrangement and details of construction, method of heating, disposition of gas and water pipes, &c. He gives also many of the principal weights, as well as the cost of construction.

The following list of plates will, with the accompanying memoranda, afford an idea of the information contained in the Author's description, which extends to fifty-six quarto pages:

i. General arrangement of the works themselves and of the workmen's village.

ii. Carriage repairing shop: sections and elevations. This shop is 460 feet long, by 361 feet wide. The roof is of iron, of somewhat peculiar design, and divided into eleven nearly equal sections, each about 42 feet span and 361 feet long, supported on cast-iron columns.

iii. Details of ironwork of carriage repairing shop roof, with diagram of stresses, &c. The rise of the roof is 12·8 feet; its middle part slopes at an angle of 45° from the ridge down to about the middle of the rafter on each side; and from these points to the supports the slope is 1 in 3.

iv. Machine shop for wagon repairs: elevations and sections. This shop is about 149 feet by 75 feet, and has a wooden roof.

v. Locomotive repairing shop, with machine shop, and boiler house: elevations and sections. The principal shop is 325 feet by 178 feet, divided lengthways by rows of cast-iron columns into five sections of nearly equal width, two of which are made higher than the others, to allow room for travelling cranes to pass along their whole length. The machine shop is 213 feet by 75 feet, and has a timber roof.

vi. Smithy and boiler shop: elevations and sections. These are under one roof, about 275 feet by 129 feet.

vii. Details of iron roof for smithy and boiler shop. This is divided into three parts, having each about 42 feet span. The central part is of a common enough type of roof truss, its ends resting on built-up wrought-iron pillars, which serve to carry at their mid-height the horizontal girder for the travelling cranes. The outer parts of the roof are simple lattice girders, having throughout the same slope as the rafters of the central truss; their outer ends rest on the walls, their inner ends upon the columns just mentioned. The roof has a rise of 26·4 feet, the total rise from the ground to the ridge being about 49 feet.

viii. Iron and brass foundry: elevations and sections, with details of roof.

ix. Workmen's houses: elevations and sections of houses suitable for different classes of workman.

Besides the plates enumerated, there are details of different stores and offices; of the workmen's dining hall (a room 90 feet by 60 feet) and bath house; of various sanitary arrangements, &c.

A. B. W. K.

Proper Amount of Waterway for Culverts. By T. M. CLEEMANN.

(Proceedings of the Engineers' Club of Philadelphia, vol. i., p. 146.)

In designing culverts for a new railway great uncertainty often exists respecting the requisite area of waterway to be provided. The clearing of forests in the neighbourhood of the line doubtless increases floods, even if the rainfall remains the same, and thus the greatest flood within the memory of the oldest inhabitant may be exceeded.

The formula given in the present Paper was found to agree very well with the requirements of the watercourses on the Richmond, Fredericksburg, and Potomac railway. A is the opening of the culvert in square feet, M the drainage area in acres, C a coefficient varying from 1 in comparatively flat country to 1·6 in hilly, compact ground;

then $$A = C \sqrt{M}.$$

The following formulæ, giving approximately the relation between the drainage area and the amount of water flowing in the greatest flood, are quoted from different authorities:—

Fanning, "Treatise on Water-Supply Engineering" . . . . . $Q = 200\, M^{\frac{5}{6}}$;

Col. Dickens . . . . . $Q = 27\, C \sqrt{M}$;

Mr. Dredge . . . . . $Q = 1300 \frac{M}{L^{\frac{2}{3}}}$;

in which Q is the discharge in cubic feet per second, M the area of catchment in square miles, L its length in miles, and C a coefficient, for which Col. Dickens gives the value $8\frac{1}{4}$ for East Indian practice. A comparative table of the results obtained from the different formulæ is given by the Author, and by Mr. R. Hering in the discussion that followed.

A. T. A.

On the Tractional Resistance of Wide and of Narrow Wheels.

By M. PIERROT.

(Bulletin de l'Association des Ingénieurs sortis des Écoles spéciales de Gand, June 1879, p. 154.)

By an Act passed by the Council of the Province of North Brabant, the use of wheel tyres less than $3\frac{3}{4}$ inches in width was prohibited; for vehicles drawn by more than one horse, the width was to be not less than $4\frac{1}{3}$ inches. A general outcry was raised

against this Act, and it was judged advisable to make special experiments on the resistance of wheeled vehicles to traction, in support of the enactment. The experiments were conducted by M. Hogerwaard, who employed a four-wheel vehicle, which was fitted alternately with wheels having narrow tyres and 3¾-inch tyres. A dynamometer, consisting of an oval spring with a continuous needle-indicator, was placed between the drawbars and the body of the wagon. The wagon was drawn over three different surfaces: 1st, a clay field, lying fallow, cultivated to a great depth and thoroughly drained, covered with dung-heaps; 2nd, a clay field, in two parts, one fallow, the other cultivated; 3rd, a part of the review ground, strong clay soil, which had been turned up for some time, and was soaked with rain.

On the first ground, the leading results were as follows: The average maximum resistance of a load of 2,200 lbs. amounted to 800 lbs. with 3¾-inch tyres, and to 865 lbs. with narrow tyres. On the second ground, fallow, with a load of 1,320 lbs., the resistance amounted to 544 lbs. with 3¾-inch tyres, and to 515 lbs. with narrow tyres; on the cultivated part, the resistance rose to 675 lbs. with the wider tyres. On the third ground, with a load of 1,430 lbs., the resistance amounted to 440 lbs. and 398 lbs. respectively, on a clay road; but, on the simple clay soil, it amounted to 738 lbs. and 880 lbs.

On a good gravel road, with the same load, 1,430 lbs., the average maximum resistances amounted to 160 lbs. and 156 lbs. respectively.

In consequence of the results of these experiments, the enforcement of the Act was cheerfully accepted, and similar Acts have been passed for neighbouring districts.

D. K. C.

Wheeled Vehicles Carrying their Rails. By M. GRANDVOINNET.

(Annales du Génie civil, June 1879, p. 455.)

The system of M. Sourilas, for enabling wheels to carry their own rails, laying them down, rolling over them, and taking them up, is similar to the system of movable rails initiated by Mr. Boydell, upwards of twenty years ago. There are ten slab-rails on the circumference of each wheel, connected to it at each side by two links crossing each other, admitting of the required lapping and unlapping movement of each piece of rail. In a simplified form of attachment, there are only half the number of connecting bars.

From the results of trials by dynamometer, it appears that the tractive resistance is reduced nearly 50 per cent. by the employment of the carried rails, in traversing rather soft ground. Wagons fitted with the movable rails are recommended for localities where the cost of local railways cannot be incurred, and for farm purposes.

D. K. C.

Public Works executed by the Prussian Government during the Year 1877.

(Zeitschrift für Bauwesen, 1879, pp. 133 *et seq.*)

HARBOUR WORKS AND DAMS.

The construction of the north and south moles at Memel progressed to the extent of 109 and 328 yards respectively. They are constructed of rubble, in cement mortar, on a foundation of rif-raf. The walls have a straight batter of 1 in 4 on the landward side, and are curved on the seaward face, except towards the top, which is vertical. A footing of rubble, 6·5 and 9·8 feet wide, extends the whole length of the outer face of the wall. At the north mole the masonry is 20·6 feet wide at the top, which is 8·6 feet above the mean water level. At the south mole the width at the top is ·5 feet, increasing gradually to 9·8 feet for the first 110 yards; and at the end, where the walls are already completed, it reaches width of 16·4 feet. The height of the south mole, starting at feet above the mean water level, rises gradually up to 10·4 feet, which height remains the same to the end.

The first 437 lineal yards of masonry of the south mole were estimated at £14,500, and the following 273 lineal yards at £10,000. On both these sums a saving is expected.

In April 1877 the extension of the north and south moles on the Pillau "Seetief," in the district of Königsberg, was begun. At the end of 1876 the total length of the south mole was 00 yards; of these the first 560 yards were a complete massive construction, built partly on a foundation of loose stones and partly on old foundations. The remainder, where there is an average depth of water of 30 feet, stands on piling filled in with stones. These stones form the foundation on which the masonry is carried up in concrete blocks, rubble masonry and concrete, with a width of 25·7 feet at the top, and provided towards the sea with a breast wall 5 feet high and 4·1 feet thick.

The extension of the south mole is estimated at £137,817. The length is 642 yards, a head of 22 yards will be added, and the construction will be completed in about nine years.

The total length of the north mole was, at the end of 1876, ,039 yards. The extension of 74 yards, to which will also be added a molehead of 22 yards, is estimated at £35,424, and will probably require about five years to complete. Its construction is similar to that of the south mole.

There remain the construction of the entrance, and petroleum harbour near Pillau, which was begun in the spring of 1875. The total length of the harbour dam is 2,061 yards, of which 630 yards are complete; but the dredging of the harbour basin can only be proceeded with slowly. The petroleum harbour can at any moment be isolated from the entrance harbour by an iron pontoon.

The surrounding dam, from the point where it joins the closing dam of Old Pillau to the end of the petroleum harbour, as well as the dam of the latter, consists of an earth embankment of 65½ feet wide. The embankment is properly secured on each side, and where ships are loaded and unloaded piers are erected; the rest of the dam is made of piles braced together and filled in with stones. The cost is estimated at £169,781.

In 1872 a basin was begun in the district of Danzig, estimated at £221,388, and at the end of 1877 the works were so far advanced that the dredging was to be started at the beginning of 1878, and the first part of the basin was expected to be utilised in the same year.

Of the extension of 4,046 yards of the north-west mole, at the outfall of the river Elbing into the fresh bay, 765 yards were completed. The object of this mole is to prevent the accumulation of sand in the navigable part of the Elbing, which arises from the yearly rise of the Nogat. The mole is constructed of two rows of round piling, cross-braced and tied together; behind these is planking, and the interval is filled with loaded fascines. As a trial the planking was done away with this year for a certain distance, and the rows of piling were driven at a distance of only 3·28 instead of 9·84 feet. The channel way being irregular, the new mole could not be executed close to the same, and a new channel had to be dredged. For this purpose a small pump-dredger was provided, and the experiment was found so satisfactory that a larger pump-dredger has been ordered for these works. The cost for the construction of the mole is estimated at £13,710, and the dredging of a channel near the mole is estimated at £16,500.

In the district of Stettin, near Swinemünde, the cutting from the large bay to the Swine has proceeded since August 1874. Up to the end of 1877 there had been removed 3,113,000 cubic yards of earth, and there remained about half as much more to be excavated. The length of the cutting and of the dredging of the channel in the bay is 8,640 yards, the depth is 18·6 feet, and the width of the bottom is 246 feet. The ground to be excavated consists of compact sand and sea shells, and rises at the highest point 18·2 feet above the mean water level. As far as 3·28 feet below the mean water-level the earth is excavated by manual labour, and the water is kept down by a centrifugal pump. Below 3·28 feet the excavation is made to the full depth by a steam-dredger. Part of the excavated ground is laid on each side of the cutting, at an average distance of 328 feet from the shores; part of it is discharged into a branch of the Swine, and part is transported by boats and discharged into the open bay. The cost of the cutting is estimated at £184,500.

At the harbour of Kügenwaldermünde the construction of the new dams has been in hand since May 1873. These dams form an entrance basin of an average width of 295 yards, and a length of 434 yards. This basin is in connection with the commercial

harbour. The moles are 29½ feet wide at the water line, and consist of two tight rows of piling driven to a batter of 1 to 4; and at intervals of 8·2 feet they are tied together with galvanised wrought-iron ties, and the spaces are filled to the water line with granite, which is cased with concrete blocks containing about 141 cubic feet. At greater depths of water the masonry is entirely of granite rubble in cement mortar. Towards the sea the moles are also provided with a small breast-wall, as a security against the waves. The foundations are estimated at £77,445, and the masonry at £4,300. Of the dredging of the Wipper to the entrance of the projected harbour basins, which work of dredging is estimated to cost £13,500, up to the end of the year 75,555 yards were excavated.

In August 1877 the western basin of the projected interior harbour was begun. It is situated in front of the town of Rügenwalde, on the shore of the Wipper, and rails will be laid so as to connect it with the railway station. The dimensions are to be 640 feet long and 147 feet wide, with a depth of water of 16 feet. The cost was estimated at £21,400; and, owing to the difficulties of the piling, the works are only expected to be completed in 1879.

In the district of Stade the construction of a timber harbour was begun in 1876, the cost being estimated at £13,165, including two bridges over the communication channel (one road bridge and one railway bridge). The harbour complete occupies a surface of 6 acres, has an average depth of water of 4 feet, and is surrounded by natural embankments.

The dyke at Heinitzpold, on the Dollart, begun in 1873, and nearly completed at the end of 1876, was so damaged by the high water of January 30 and 31, 1877, that its completion was delayed until the following December, and the portion of the canal filled with mud could only be cleared out in the spring of 1878. The total cost is estimated at £154,500, including £13,500 for the Wymeer works.

In the province of Silesia the strengthening works on the Süderheverskoog dyke, begun in April 1876, were continued. The Süderheverkoog has an area of about 607 acres. The dyke is 13 feet wide at the top, and has an average height of 17 feet. The works will be completed in three years, and are estimated to cost £10,500.

In the district of Husum, on the Northstrand Island, the construction of stone dykes was begun in 1874 on the Silesian west coast; viz., on two points advancing towards west and north-west, which are greatly exposed to the waves. These works were fairly advanced in 1877, but will hardly be completed before 1880. The estimate amounts to about £24,500.

In the district of Plön, Oldenburg, the embanking of the low grounds of Fehmarn, begun in 1874, was completed in 1877. An area of 988 acres is thus protected against high water. The dyke, built of clay, is 5,140 yards long, and for 765 yards near Sulsdorf

crosses the sea at a depth of 2 feet. It is provided with two sluices. The works are estimated at £7,911.

In the same district the embanking of the northern low grounds of Fehmarm is in progress, and only about 3,280 yards on the northern bay remained to be completed. This portion is proposed to be made with a hearting of sand cased with clay, which has to be brought from a great distance. The entire length of the dyke is about 9 miles, and it has to protect against high tides an area of about 3,700 acres of fertile land. Two massive sluices are provided, each with two openings of 10 square feet. The estimate of £18,000 is expected to be surpassed by about £3,750.

The embankment and the drainage of the low parts of Klosterlake was begun in 1877, to protect inundated places as well as the three low-lying villages which were partly destroyed during the high sea of the 13th of November, 1872. The surface inundated by the high tide in question embraces an area of 3,590 acres, of which 988 acres lay in the Klosterlake. The dyke is 10,170 yards long, with a width at the top of 10 feet. As a protection against the strongest seas the dyke is constructed behind the dunes, about 500 feet from the sea; and at such places where the dyke could not be built at a proper distance, the foreshore was made broader by small dykes. The drainage area of the large sea-sluice embraces 9,478 acres, and the area of the smaller sluices embraces 3,667 acres. The Klosterlake is drained by pumping, and by emptying the water in the Baltic Sea. The water running freely away is led round the Klosterlake through a ring canal 7,655 yards long. The cost of the dams is estimated at £43,500.

Lastly, there is the embankment and the drainage of the low grounds of Waterneversdorf-Neudorf, in the district of Ploen, begun in 1876 and continued in 1877. The dyking is to protect an area of 2,567 acres, principally composed of parts belonging to Waterneversdorf and Neudorf, and of small parts which belong to the town of Lütjenburg. The large lake, having a surface of 1,368 acres, is included in the protected area. The dyke is composed of three separate parts, which are 2,132 yards, 1,804 yards, and 109 yards in length respectively. There are two sluices for the drainage, and the cost is estimated at £12,225.

E. K.

Floating Dock, Saigon, Cochin China.

(Portefeuille économique des Machines, 1879, p. 98.)

The iron floating dock now being erected at Saigon by Messrs. Schneider and Co., of Creusot, is to replace a smaller one furnished by an English firm in 1862, and now nearly worn out. The principal dimensions of the new dock are: length, 393 feet 8 inches; width outside the walls, 98 feet 5 inches; height, 49 feet 2 inches. It is of rectangular section, with an available inside width of

75½ feet, and height of 37 feet. At intervals of 16 feet along the junction of the walls and floor of the dock are equal-sided boiler-plate gusset pieces, rising to three-eighths of the height of the walls. The spaces between are further divided into eight smaller intervals by seven partitions, coinciding with the boiler-plate gusset pieces, but consisting alternately of lattice-work and of simple transoms. Longitudinal and transverse bulkheads divide the dock into ninety-six water-tight compartments. At distances of about 4 feet are provided the usual timbers, chocks, &c., forming the cradle to take the vessel, and altars are constructed along the walls in sufficient number to allow of working at any height. A complete system of pipes is provided, communicating by sluices with each of the ninety-six water-tight compartments. The two main pipes are laid along each side of the bottom of the dock, and communicate at the centre of their length with the sea, and with the centrifugal pumps established inside the dock walls at mid-level. There are two pumps on each side of the dock, worked by 90-HP. engines, taking steam from semi-portable boilers on the top of the dock walls, duplicated, so that each may be used alternately. The engines are direct-acting, high-pressure, with double cylinders and fly wheels; the cylinders are 17 inches in diameter, with a length of stroke of 12½ inches; the diameter of the centrifugal pumps is 45 inches, and the average number of revolutions per minute is one hundred and eighty-five.

All the ironwork is galvanised, so as to resist oxidation as long as possible. The dock is capable of taking vessels of any displacement, up to 6,000 metric tons. The total weight of the structure is estimated at 4,500 tons, and it cost £132,000.

F. G. D.

NOTE.—The form and dimensions of the new Saigon dock accord pretty closely with those of similar works at Cartagena and Ferrol, costing between £150,000 and £160,000; but the latter docks, though not so long were wider, their equipments were more complete, and the cost of iron at the time of their erection was much greater.—*Vide* Minutes of Proceedings Inst. C.E. vol. xxxi., p. 295.

Notes on the Works of the Maritime Station at Venice.

(Il Politecnico, vol. xxvii., p. 321.)

The passage of the Brenner, and the opening of the Suez Canal, must restore to Venice, in the opinion of the Italian engineers, at least a portion of her former commercial importance. But to effect this it is requisite to improve the harbour, to enlarge the canals, to construct warehouses, and to arrange the most perfect communication between the railway and the quays.

The large sums of money expended by the Austrian Government in the formation of a new port at Trieste have been regarded by the Italian Government as involving the necessity for com-

pleting the railway arrangements of the port of Venice; and a line to connect the railway station with the banks, called Zattere (floats), to the south of the great canal of La Giudecca was in consequence designed. This project gives a length of railway wharfage of above 280 yards, but there is no room for sidings, or for further development. In 1857 the Italian Government appointed a Commission, of which Paleocapa was the President, to examine the question. The Report of the Commission was hostile to the Zattere project, as being altogether defective. It was calculated, from the experience of various harbours, in and out of Italy, that the maximum amount of regular business that could be conducted on a quay of the kind contemplated was 27,000 tons per 100 mètres (328 feet) of length. On this basis, the completion of the Zattere project would not provide for more than 71,800 tons per annum, supposing the work to be unintermittent.

Abandoning the project of the Zattere, the Commission proposed the construction of a large basin in the part of the lagoon fronting the Campo di Marte, which should be put in communication with the Della Giudecca canal by a new cut, and with the railway station by a bridge over the Canale Grande. Considerable opposition being raised to this project, another Commission was appointed in 1868, under the presidency of the Prefect of Venice, which reported, with only one dissentient voice, in favour of Signor Paleocapa's plan. A convention was accordingly stipulated, on the 4th of October, 1868, with the Alta Italia Railway Company for the execution of this project.

The plan in question is described in detail in the Paper the account being illustrated by several plans and drawings. The length of the basin is 790 yards, the width 214 yards, and the depth 26 feet. A large mole, also 790 yards long, and 100 yards wide, divides the basin from the Canal Scomenzera, which is enlarged to a width of 50 yards, and to a depth of 13 feet. The mole is protected by a wall, on either side, for 550 yards, the remainder of the length being protected by piling. Five warehouses are to be erected on the walled part of the mole, the level of the surface of which is 7·9 feet above ordinary high-water mark. Two lines of railway are led from the station over the new bridge crossing the Canale Grande, and diverge into fourteen lines, of varying lengths, laid through and between the warehouses and over the mole. Thus the mole is accessible, on the side of the basin, to ships drawing nearly 26 feet of water, and on the side of the canal, to craft of half that draught, foreign and coasting traffic being thus conveniently provided for. As the exigences of commerce increase, it will be possible to increase the length of quay wall, in different positions, by a total length of 1,100 yards. The actual length of quay is 675 yards of 26 feet depth, and 550 yards of 13 feet depth.

The area of the maritime station is 4,224,000 square yards, the whole of which is covered by the tide to the depth of 9 inches at low, and of 33 inches at high, water. It is traversed for its entire

length by the canal called Dei Baranei. Soundings show a depth of 26 feet of sand and mud over the space. The material has been excavated to the depth of 4 feet 6 inches, by long spoons, or mud shovels, and below that level by dredging machines of from 40 HP. to 80 HP., according to the depth.

The quay wall of the basin is composed of three kinds of work. The foundation, to height of 6 feet 6 inches, consists of four layers of loose stone, each layer being arranged and levelled by divers, who are furnished with the Rouquayral-Denayrouze apparatus,[1] made at Paris. Each diver receives a daily pay of 2*s.* 6*d.*, with an additional allowance of 1*s.* 3*d.* for every hour he is in the water. The time spent in the water each day averages six hours and three-quarters, and the time employed in levelling a cubic yard of the stone is twenty-two minutes. The cost of the stone, on the spot, is 5·75 lire per cubic mètre; and the cost of the foundation when finished is 8·0 lire per cubic mètre, or equal to about 8*s.* 8*d.* per cubic yard.

On this foundation are erected four courses of blocks of artificial stone, the lowest of which is 13 feet, the second 12 feet 6 inches, the third 11 feet 8 inches, and the fourth 11 feet 2 inches long, the width of each block being 6·66 feet, and the height 4 feet 8 inches. The blocks are composed as follows: hydraulic lime of Polazzolo, 35 parts; sand from the river Brenta, 50 parts: pozzolana of S. Paolo di Roma, 50 parts. It is mixed with fresh water, and beaten in wooden moulds or boxes. The blocks are lowered into place by a travelling crane; the length of each block forming the thickness of the wall. The cost of the blocks unfixed came to 22 lire per cubic mètre, which the cost of fixing raised to 28·90 lire per mètre, or about 37*s.* 6*d.* per cubic yard. On the upper course of these blocks is built a wall of wrought stone, 10 feet high, coped with granite from the island Del Giglio. The quay wall of the mole on the side facing the canal is built on larch piles, and the cost amounted to 310 lire per square mètre of wall, or £15 10*s.* per square yard.

For the support of the warehouses the method adopted was that of sinking wells—lined with brickwork, and filled with concrete —down to the clay which underlies the sand and silt of the lagoon. The cost of this foundation—of which full details, both of design and execution, are given in the Paper—was 63·20 lire per square mètre, or about £3 3*s.* per superficial yard. Each of the five warehouses was 55 yards long and 33 yards broad; and the cost was 89·96 lire per square mètre, or about £4 10*s.* per square yard. An additional cost of 4*s.* 9*d.* per square yard was incurred for a portion of the foundations of these buildings.

The iron bridge to carry the railway from the mole over the Canale Grande has two openings, of 29·313 mètres, or 96¼ feet each, the foundations being on larch piles. The calculations of the form of the girders, and other details of the bridge, are minutely

[1] *Vide* Minutes of Proceedings, vol. xliv., p. 325.

given in the Paper. The total cost was £10,132, or £158 for each yard of span. Of this the foundations cost 30·5 per cent, and the ironwork 49·80 per cent. There is also an iron footway bridge, of 82 feet span, over the Scomenzera canal, erected at a cost of £1,672, of which the temporary work and foundation cost 32·5 per cent., and the ironwork 27·1 per cent. Particulars are also given of the railway laid on the mole, and of various subsidiary works.

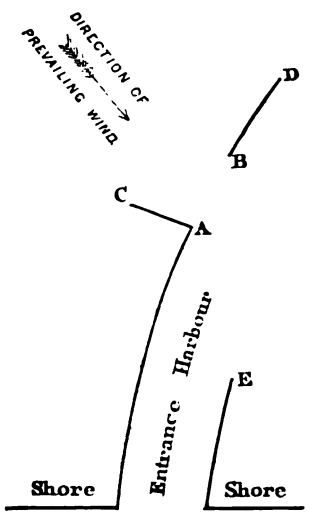
The maritime station has been now for some time complete, but at the date of this report (which was written in February, and published in July 1879), improvements were required in the canal giving access to the basin, which had not been taken out to its requisite depth or width. The total cost of the station is not stated in the Paper. It is remarked that a sum is allotted in the budget of the Ministry of Public Works for the current year, which will be sufficient to complete the dredging of the entrance canal; and it is hoped that it will not be long before the basin is open for commercial traffic.

F. R. C.

A New Design for Harbour Entrances. By A. Cialdi.

(Annales industrielles, June 1, 1879.)

The method proposed for sheltering and maintaining the entrance to a navigable channel by means of a solid breakwater is shown on the accompanying sketch. On a shore where there is a drift of material along the coast in the direction of the prevailing wind, open breakwaters on piers and arches are sometimes constructed, to allow the drifting sand a free passage, so that it may not accumulate in front of the entrance. The openings, however, produce an agitation of the water in the harbour, which interferes with the loading and unloading of vessels; and the waves which bring the silt through the openings cannot preserve their force of translation sufficiently to convey the silt entirely beyond the harbour. The records and remains of the harbours built by the Romans indicate that, whilst constructing the pier on the lee side of the harbour with openings to favour the exit of sand and silt brought down by the river flowing into the harbour, they used to make a solid breakwater on the side exposed to the prevailing wind. The breakwaters at the mouth of the Tiber and at



Civita Vecchia are instances of this method of construction. The Author points out, however, that his design is quite distinct from the form adopted by the Romans, in possessing an opening, A B, in the windward breakwater, and a return wall, A C. The waves passing between C and D would be forced through the opening A B, being intensified and guided by the return wall, and would keep the entrance to the harbour free from deposit. Also, the opening being at some distance from the shore, and consequently in deeper water, only the lighter materials would drift through the opening and be readily carried beyond the harbour. Moreover, the breakwater, being solid, would form a perfect shelter for vessels lying alongside in the harbour, and the opening furnishes a second entrance to the harbour. For these reasons the Author considers the proposed design superior both to the breakwaters with openings and to the old Roman system.

L. V. H.

The United States Drilling Scow, East River.

(Scientific American, July 19, 1879.)

At the commencement of the works for reducing the reefs obstructing the East River portion of New York harbour, surface blasting was tried, but, proving a failure, speedily gave place to a system of deep drilling from platforms fixed over the rock. It was, however, found that the devices adopted for protecting the divers and steadying the drill proved inadequate, owing to constant collisions with passing vessels; and after various attempts at improvement, the fixed platform was abandoned in favour of a specially-designed scow and drilling apparatus. The vessel is of great size and massive build, and is furnished with an overhanging guard faced with iron, as a protection against collisions, which are of almost daily occurrence, owing to the severity of the tides and the narrowness of the channel. It constitutes at once a boat, a machine shop, and a fortification. [The dimensions are not given, but the illustrations show a rectangular pontoon, about 125 feet long and 65 feet wide, furnished with a stout mast and derrick shears.] In the centre of the scow is a well hole, 32 feet in diameter, in which is hung a truncated hemispherical dome of boiler-plate, 30 feet in diameter, open at the top and bottom, and carrying a number of strong iron tubes, disposed vertically, for the protection of the drills. Round the lower part of the dome are arranged twelve iron movable prong legs, held by self-acting cams; so that when one edge of the dome touches the reef to be operated upon, the legs can be let fall simultaneously, and on reaching the ground are securely locked, thus maintaining the dome in an upright position. The hemispherical shape was adopted on account of its superior stability under the action of strong currents. The trans-

verse pressure of the latter is converted into radial pressure, which, acting downwards, tends to maintain the dome in equilibrium. The drill engines are mounted on a timber framework inclosing the well, in such a way that they can be placed directly over the end of the fixed drill tubes which may offer the best positions for working; but within the range of the 15-feet circular opening at the top of the dome the drill tubes may themselves be moved to any desired position. The drills and rods are together about 10 feet long, and weigh between 600 lbs. and 700 lbs. each. They are connected to the piston rods of the drill engines by ropes, a flexible attachment being necessary on account of the swaying movement of the scow, and the rise and fall of the tide. The cutting edges of the drills are cruciform, 5½ inches by 5½ inches: they act by impact from a fall of between 2 and 3 feet.

When the site of a blast has been fixed by divers, the scow is securely anchored above it, and the dome, being lowered, is unhooked from its supporting chains. The drilling engines are then placed in position, the rods attached, and the work set going. The average penetration of the drills during an eight-hour shift is from 7 to 10 feet, one sharpening of the bit generally sufficing. When the drilling is completed, the diver stops the holes with wooden plugs, to prevent the admission of sand and mud, connecting each plug by cords, and the last one to a line to the surface. The chains are then hooked to the dome, and the scow swung out of position, or taken to some other reef. The charges, inclosed in tin cases 10 feet long, and 5 inches tapering to 4 inches in diameter, are conveyed to the site of the blast on a small scow. Guided by the main line of the stoppers, the diver at slack water descends to the first line of the stoppers and inserts the charges in succession. On his return to the surface the blast is fired from an exploding battery on board the scow, which has been previously withdrawn to a safe distance. The effect of the blast is the elevation of the water over the reef in a huge circular mound, which instantly bursts, sending up, from 50 to 100 feet into the air, a great spiral column of foam, water, and rock fragments. The broken rock is afterwards removed by grapnels. As many as twenty-one holes have been simultaneously fired, with a total charge of 1,140 lbs. of nitroglycerine, at Diamond reef, which has been, over a considerable extent, reduced to the 26-foot level at low water. During the past three years, although much time has been lost for lack of appropriations, the following obstructions have also been reduced: Way's Reef, from 17 to 26 feet; Coenties Reef, from 15 to 25 feet; and Harlem River Rock, from 9 to 14 feet. Much work has also been done on Pot Rock and the Frying Pan.

F. G. D.

Hydraulic Brake at the Aubois Lock. By A. DE CALIGNY.

(Comptes rendus de l'Académie des Sciences, vol. lxxxviii., p. 1245.)

Mention has been made, in a previous communication on the Aubois lock,[1] of a proposal to use a hydraulic brake for causing the pipes, in the apparatus for saving water in locking, to drop quietly on to their seats without any shock or rebound. This has since been successfully accomplished, without the aid of a valve, by employing a brake consisting of a wooden inverted truncated cone moving in a vertical sheet-iron cylinder filled with water. The cylinder is 1 foot 8 inches high, and 8 inches in diameter; it is fastened at the bottom to an iron plate firmly fixed on the ground, and has a sheet-iron lid. The upper part of the cone, which is cylindrical for a length of $\frac{3}{8}$ inch, has a diameter of $7\frac{1}{2}$ inches and a length of 8 inches. An iron rod is inserted in the axis of the cone; it is fastened by a nut at the bottom, and passes through a hole in the centre of the lid of the cylinder, and has a cord attached to it at the top. When the counterpoise of each great movable pipe of the apparatus approaches its highest point, the cord attached to the cone is abruptly pulled tight, and the descent of the pipe is checked by the resistance the cone experiences in rising in the cylinder. The cone is sufficiently weighted by the rod to sink to the bottom of the cylinder when the cord is slackened. By increasing the distance traversed by the cone, the fall of the pipe on to its seat can be rendered as easy as desired, without its tightness on its seat, when once reached, being at all affected.

L. V. H.

Irrigation in the South of France. By G. DUMONT.

(Annales du Génie civile, July 1879, p. 497.)

This article furnishes a concise account of the various irrigation works already executed in the departments of the Isère, the Drôme, and Vaucluse. It also contains an account of the proposed Rhone irrigation canal, which appears likely to be shortly commenced, for the purpose of supplying water to the departments of the Hérault and Gard, which are at present destitute of any supply, and also for completing the irrigation of the departments mentioned above.

In the department of the Isère there are several large irrigation canals, of which the Romanche is the most important; its length is nearly 8 miles, and it irrigates about 2,360 acres. In the department of the Drôme there are the Pierrelatte and Bourne canals.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lvi., p. 337.

The former was commenced about the close of the seventeenth century, and, having been abandoned, was filled up during the first Revolution. It was subsequently reopened, and was taken up by a company in 1838, but failing to pay working expenses, it was sequestered by the Government in 1861. Now it is proposed to enlarge and extend it. The canal is 10 miles long, and capable of irrigating 6,180 acres, but only 740 acres are actually supplied. The Bourne canal is being constructed by a local company, and is nearly completed. It is intended to irrigate a plain lying to the south of the Isère, between the Rhone and the Alps, 54,000 acres in extent. The charge is fixed at £2 per annum for a supply of 13 gallons of water per minute for periodical waterings. Water may also be furnished from the canal for domestic purposes, and the falls used as a source of power. The irrigation works in the department of Vaucluse are numerous and extensive, and some are of ancient date.

The Rhone irrigation canal is to convey a supply of 7,700 gallons per second, of which 4,400 gallons are to be drawn from the Isère, and 3,300 gallons from the Rhone, and is intended to irrigate 111,000 acres. The yearly charge for irrigating per acre has been fixed at £1 0*s.* 9*d.* The Rhone is specially suitable as a source of supply for irrigation, as it is swollen by the melting of the snow in the summer months when water is needed for irrigating, and its smallest flow occurs in December and January, when the land does not need water.

L. V. H.

Trial of a Corliss Engine.

Report by MM. WALTHER-MEUNIER and G. KELLER.

(Bulletin de la Société Industrielle de Mulhouse, vol. xlviii. p. 910.)

The tests described extended over twelve days in April and May 1878, and their results are given with great fulness. The engine tested was made by Messrs. Berger-André and Co., of Thann, and had been, at the time of the experiments, working for about six months in the spinning mill of Messrs. Schlumberger, Son and Co., of Mulhouse. It was an ordinary double Corliss engine, with two equal cylinders working cranks on the ends of the same shaft. One of the cylinders only was tested, the other being used to keep the speed uniform, the governor of the first being thrown out of gear so as to maintain a constant cut-off. The cylinder was 2 feet in diameter, with a stroke of 4 feet, and was jacketed both at the side and ends; the piston was also heated by steam.

Three sets of tests were carried out: the first to measure the amount of work required to drive the engine itself under different circumstances; the second to measure the quantity of steam used

by the engine, as well as the duty done by the boiler; and the third to check the second as to steam consumption.

The first trials lasted only one day. Six short experiments were made in which the engine worked against the resistance of two friction brakes. The following are the results of these experiments:

Total indicated HP. . . .	72·8	102·0	119·5	133·3	145·4	158·4
Indicated HP. taken up by engine and shaft . . .	12·4	12·2	13·5	11·8	12·4	13·6
Efficiency . . . per cent.	83·0	88·1	88·4	91·1	91·4	91·5

The speed was fifty revolutions per minute in each case, varying very slightly. The governor was in gear, and the second engine was disconnected. The power credited to the engine includes that necessary to drive the second shaft (a pinion on which geared with the fly wheel), on which the brakes were placed.

The next series of experiments lasted five days, the average duration of each being about nine hours forty minutes. The final series lasted six days, the average duration of each being a little over nine hours. In the first of these the feed was measured directly, and at the same time the discharge was also measured, so as to afford a check on the steam consumption as calculated from the direct measurements. The discharge observations, however, were not available for this purpose, on account of some accident to one of the thermometers. The final series of experiments was, however, carried out on both systems without accident, and the two sets of measurements agree exceedingly well. The measurements of the duty of the boiler are given in a table, but are not considered trustworthy, on account of some apparent leakage of gas from an adjacent flue.

The following are the principal results arrived at:

(*a.*) *Effect of the steam jacket.*—During two days' trial without the jacket, the engine indicated 129·4 HP.; the mean quantity of water used (measured as feed) was 24·38 lbs. per indicated HP. per hour. During the next day with the jacket, the indicated power being 159·3 HP., the consumption was reduced to 19·58 lbs. per indicated HP. per hour. On the day following, when the jacket was kept better clear of water, the consumption was 18·7 lbs. per indicated HP. per hour, showing a mean difference in favour of the jacket of about 21·5 per cent. Experiments at lower powers gave for 82 indicated HP. without jacket, 26·8 lbs. of steam, and for 102 indicated HP. with jacket, 18·7 lbs. of steam, per HP. per hour—the difference being about 30·5 per cent. in favour of the jacket.

(*b.*) *Effect of heating the piston.*—At full powers (159 to 163 indicated HP.) this showed no economy; at low powers (100 to 105 indicated HP.), an economy of about 2·2 per cent. The observers

consider that, for engines of this type, there does not appear to be sufficient saving to counterbalance the additional complication rendered necessary by the adoption of any system of piston heating.

(*c.*) *Effect of insufficient draining of the jacket.*—The experiments show that this cause alone may add from 2 to 4 per cent. to the consumption of the engine, by decreasing the efficiency of the jacket.

(*d.*) *Water carried over by the steam.*—A number of measurements were made, but their results are somewhat irregular, varying from 1·5 to 6·2 per cent.

(*e.*) *Average working of the engine.*—The mean consumption of steam by the engine during eight days (eighty-five hours of work), with a variation of work from 105 to 163 indicated HP., was 18·7 lbs. per (French) HP. per hour, the jacket being in use on all days.

It should be mentioned that there appear some errors in the tables, so that the results should be checked (fortunately all the data are given) by any one who wishes to use them.

A. B. W. K.

Apparatus for Tracing at a distance Curves representing the Work done by the Steam within the Cylinders of Locomotive Engines.

By M. DEPREZ.

(Annales Télégraphiques, vol. vi., p. 56.)

The ordinary steam-engine indicator suffices, when applied to engines running at moderate speeds, but is liable to error as the velocity increases, until, at a speed of two hundred and fifty revolutions per minute[1]—a very common speed for express locomotive engines—its readings cease to be trustworthy.

In order to remedy these defects, M. Marcel Deprez has, by calling in the aid of electricity, constructed an instrument which, at any speed, traces, in an experiment-van attached to the train, a curve of which the abscissæ are proportional to the path travelled by the piston of the locomotive, and the ordinates are proportional to the steam pressure upon the piston.

In designing the instrument, M. Deprez kept before him the following requirements: First, to give to a sheet or band of paper moving beneath a stile, and upon which the curve is to be traced, a motion exactly proportional to that of the piston of the engine; and second, to measure, at any instant of time, the exact pressure of the steam upon the piston. As the motion of the pistons of a locomotive is determined by the angular motion of the cranks, and therefore of the wheels, all that is necessary is to give to a wheel fixed in the experiment-van a speed of rotation precisely equal to

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[1] *Vide* Trans. Inst. Naval Architects, vol. xiii., p. 271, where the diagrams are given from the engines of the "Miranda," when making six hundred revolutions per minute.—SEC. INST. C.E.

that of the wheels of the locomotives, in order to produce a *fac simile* of the motion of the pistons. For this purpose the wheels of the experiment-van are so arranged as to transmit to the apparatus inside two distinct circular motions; the one very nearly equal in speed to that of the wheels of the locomotive; and the other, much slower than that, is transmitted to a revolving face-wheel, which drives by friction a little roller, called the correcting wheel (*roulette correcteur*), the distance of which from the centre of the face-wheel can be regulated by a screw. These two motions, the one nearly equal in speed to that of the locomotive wheels, and the other a great deal slower, are combined by means of differential gearing, so that, by transmitting their algebraic sum a remittent to the axis of the recording apparatus, the speed of the latter can be brought absolutely to that of the crank shaft of the engine. To the axis of the recording instrument, and revolving with it, is attached a disk-wheel, upon which is fixed radially a small vacuum tube; and below the driving shaft of the engine is a little electrical apparatus, which, by being acted on by a cam fixed on the shaft, interrupts the circuit with the primary wire of an induction coil, and thereby causes a discharge, or flash, to traverse the vacuum tube on the recording apparatus, which is in circuit with the secondary wire of the same coil. From this arrangement it follows, that if the speed of rotation of the vacuum tube be exactly equal to that of the driving shaft of the engine, the flash will always take place when the tube is in the same position with regard to space; and when the position of the flash varies it is a sign that there is a difference between the two speeds, and the adjusting screw has to be turned until the luminous flash becomes stationary. It is, moreover, necessary that the flash, besides occurring always at one position of the revolution of the disk-wheel to which it is attached, should always take place at one definite pre-determined position; so that, while the stationary nature of the flash is an indication that the recording instrument is adjusted to the same speed as the driving shaft of the locomotive, its position at any moment with respect to the revolution of the disk indicates the angular position of the crank of the locomotive, and therefore the position of its corresponding piston with respect to the length of its stroke. In order to complete this final adjustment the apparatus is fitted with a second train of differential gearing, by which the position of the flash within the rotatory vacuum tube can, without stopping the apparatus, be brought to take place at any predetermined position in its revolution.

The apparatus above described is simply to insure absolute uniformity of speed between the driving shaft of the engine and the spindle corresponding to it in the recording instrument. The method by which the steam pressure upon the pistons is measured and recorded at any instant of time is as follows. To each end of the cylinder is attached a small chamber, divided horizontally into two distinct parts by means of a very thin circular diaphragm of steel; of these two parts the lower is in communication with the

interior of the cylinder, and the upper with a reservoir of compressed air situated within the experiment-van, and of which the pressure can be varied at will. It follows, then, that whenever the pressure in the upper portion of the chamber is greater than in the lower portion—in other words, when the pressure in the air reservoir is in excess of that in the cylinder—the diaphragm will be deflected downwards; and whenever the steam pressure is greater than the air pressure the deflection will be in an upward direction, it being impossible for the diaphragm to occupy a central or neutral position, except when the pressure in the upper and lower portions of the chamber are equal. The amplitude of deflection of the diaphragm is limited to from 1 to 2 millimètres (0·039 to 0·079 inch) by two metallic stops, which serve as electrical contact pieces, so connected that whenever the centre of the diaphragm rests against either of them, a current of electricity is transmitted through the coils of an electro-magnet in the recording apparatus, by which a pricking point is held away from the sheet of paper which is being moved, with a motion proportional to that of the piston; and the moment the diaphragm leaves one of its contact studs, so as to be in contact with neither, the current is thereby interrupted, and a puncture is made on the paper. Thus the indicator makes a mark on the paper when equilibrium is established between the pressure within the steam cylinder and that of the compressed air which actuates the piston of an ordinary indicator, and to this piston is attached the pricking point, and thus the paper is pricked at a point corresponding to the pressure at that moment; and as the paper is moved, in a direction parallel to the abscissæ, to a distance proportional to the path of the piston during its stroke, a point in the curve, or indicator diagram, is traced. For each point obtained in the curve the pressure must be varied.

The instrument above described is capable of tracing the two curves representing the work done on the two faces of the same piston, by so arranging the electrical connections that the current is transmitted by both the diaphragms in series, so that a movement of either interrupts the circuit and transmits a signal.

C. W. C.

The Law of Geothermic Progression. By P. Van Dijk.

(Revue universelle des Mines, 1878-79, vol. iv., p. 391; and vol. v., p. 46.)

Under this general title, employed to signify the relation which the subterranean temperature of the earth bears to the depth below its surface, the Author investigates first the theoretical transmission of central heat outwards through the earth's solid crust, from its highly heated core in a state of ignition or fusion; and secondly the inverse transmission of external cold inwards. The expression "geothermic scale" (German *geothermische Tiefenstufe*,

and French *échelon géothermique*) being taken to denote, at any distance below the earth's surface, the additional depth which at that point corresponds with a rise of 1° in temperature, he shows that the geothermic scale will increase, according to the first mode of investigation, with increasing distance outwards from the hot core; and, according to the second mode, with increasing depth below the surface.

The outward transmission of central heat is amenable to theoretical investigation alone, as regards that portion of its vast range which is by far the largest, and in which its effects would be by far the most noticeable; and it is only at the remotest extremity of its range, within the comparatively insignificant depths accessible from the earth's surface, that deductions from this theory can be confronted with observed facts. The results of the equations arrived at by the Author for the outward transmission of central heat, representing curves of hyperbolic character, would be a practically uniform geothermic scale throughout the greatest depth accessible; while, even if the observed temperature continued appreciably constant down to that depth from the surface, instead of increasing with the depth, such a condition would not preclude the existence of a fused or fiery core. Moreover, if the earth were entirely solid to its very centre, the temperature at that point would then have to be infinitely high.

The inward penetration of external cold, on the other hand, admits at once of investigation by theoretical and by practical methods; and it is within the most effective portion of its range, namely down to the depths accessible from the earth's surface, that deductions arrived at from this theory can be verified or corrected by observations made in sinkings which have been executed to various depths in different parts of the world. The available observations employed for this purpose by the Author are collected by him into the accompanying Table. The data obtained from the bore holes in the island of Java are the results of observations made by M. Ermeling, engineer officer, by M. Hooze, mining engineer, and by the Author himself, who is mining engineer-in-chief in the Dutch East Indies. The data from the Sperenberg bore hole have previously [1] been quoted; others are taken from Naumann.[2]

A glance at the concluding column of this Table suffices to show, that the geothermic scale increases with the depth in every observation here noted. Former representations of a uniform rise in temperature proportional to the increase in depth, giving a constant scale which was roughly stated at 30 mètres depth per degree centigrade or 55 feet per degree Fahr., are thus confuted at the outset, not only in regard to any individual locality, but also in comparing widely diverse regions; for while that value of the geothermic scale would be nearly reached at Yakutsk at 400 feet

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. liii., p. 389; and 'Zeitschrift für das Berg-, Hütten- und Salinen-Wesen,' vol. xxv., p. 58.

[2] Lehrbuch der Geognosie.

TABLE of OBSERVED SUBTERRANEAN TEMPERATURES, and CORRESPONDING INCREASE of GEOTHERMIC SCALE.

Bore hole or Well.	Depths below surface.		Temperatures noted.		Geothermic Scale.	
	Mètres.	*Feet.*	Centigrade.	*Fahr.*	Mètres per deg. Cent.	*Feet per deg. Fahr.*
Bore holes at Batavia, and at Grissée, in Java. Latitude 6° S.	0	0	26·0	78·8	12·5	22·7
	70	230	31·6	88·9	15·6	28·4
	140	459	36·1	97·0	18·0	32·8
	165	541	37·5	99·5	20·0	36·4
	416	1,364	48·0	118·4	31·2	56·8
	728	2,388	58·0	136·4		
Artesian bore hole at Grenelle, Paris. Latitude 49° N.	0	0	10·7	51·3	25·9	47·1
	298	977	22·2	72·0	45·3	82·4
	547	1,794	27·7	81·9		
Bore hole at Neusalzwerk, in Westphalia.	0	0	10·0	50·0	19·5	35·5
	189	620	19·7	67·5	29·7	54·1
	418	1,371	27·5	81·5	45·7	83·2
	697	2,286	33·6	92·5		
Bore hole at Rüdersdorf, near Berlin. Latitude 52° N.	0	0	9·1	48·4	15·5	28·2
	124	407	17·1	62·8	25·3	46·0
	286	938	23·5	74·3		
Bore hole at Sperenberg, near Berlin. Latitude 52° N.	0	0	9·0	48·2	17·4	31·7
	220	722	21·6	70·9	26·0	47·3
	345	1,132	26·4	80·0	33·4	60·8
	659	2,162	35·8	96·4	37·8	68·8
	1,064	3.490	46·5	115·7		
Well at Yakutsk, in Siberia. Latitude 62° N.	0	0	−10·3	13·5	7·2	13·0
	15	50	− 8·2	17·2	10·9	19·8
	30	100	− 6·8	19·8	15·2	27·7
	45	150	− 5·8	21·6	19·1	34·8
	60	200	− 5·0	23·0	21·6	39·0
	75	250	− 4·3	24·3	28·8	52·4
	116	382	− 2·9	26·8		

depth, it is not attained till 1,400 feet at Neusalzwerk and 2,300 feet in Java. From this observed increase of the geothermic scale in higher latitudes, where the mean annual temperature of the locality is lower, it may be inferred that the earth's crust is probably thicker in polar regions, and thinner near the equator.

Plotting in the form of diagrams the principal data in the Table, the Author tries how closely the curves so obtained can be fitted by hyperbolic, logarithmic, and parabolic curves; and thereby arrives at presumptive evidence in corroboration or otherwise of certain of the observed data thus employed. From his previous equations for the outward transmission of central heat, he deduces a hyperbola as representing also the inverse penetration of external cold into a solidified sphere formerly hot and now cooling from its surface inwards. But the idea of the earth's solidity throughout to its very centre, already seen to be irreconcileable with the theory of the outward transmission of central heat, is equally incompatible with the observed inward penetration of cold, inasmuch as the geothermic progression deduced from the observations in Java would assign to the earth's solid centre a temperature not exceeding the boiling point of water.

Law of Geothermic Progression.—For the complete curve of geothermic progression therefore the Author combines these two inverse modes of investigation; and by this means he finds the relation between the depth x below the earth's surface, and the corresponding temperature y, to be exactly represented by the equation

$$y = \frac{T R^2 + C R x}{(R - x)^2} - \frac{H (T - t)}{H + x},$$

where R is the earth's radius, and C, H, T, t, are constants for any individual bore-hole, t being the observed surface temperature in that particular locality, and T the temperature communicated to the surface at that place from the earth's hot core. The equation represents indeed simply the difference between the hyperbolic curve $y_1 = \frac{T R^2 + C R x}{(R - x)^2}$, already arrived at by the Author for the outward transmission of heat through the earth's crust from its hot core, and the true hyperbola $y_2 = \frac{H (T - t)}{H + x}$, representing the inward penetration of cold from the earth's surface; and H is the height above the earth's surface of the temperature asymptote to this hyperbola of cold penetration. The three constants, C, H, T, are determined by assigning any three pairs of observed values to x and y; and the three temperature observations employed for the purpose should be taken as wide apart in depth as possible. The tedious determination of these constants is much simplified, without materially impairing the correctness of the results, by noting that the extreme depth included in the foregoing Table does not exceed 3,500 feet; and that as far as 1,760 feet depth at least, or

one-third of a mile, the fraction $\frac{x}{R} = \frac{1}{12,000}$ may be neglected in comparison with unity. Then the above equation for the law of geothermic progression assumes the simpler form

$$y = T + \frac{C}{R}x - \frac{H(T - t)}{H + x}.$$

The complete curve of geothermic progression presents a point of inflexion, at which the geothermic scale will attain its maximum value. Considering by how very large an amount the temperature of the earth's fused or igneous core, even if assumed no higher than 3,000° C. or 5,000° F., exceeds the surface temperature, in comparison with the difference between the surface temperature and the absolute cold of the universe (— 276° C. or — 465° F.), it follows that the point of inflexion in the geothermic curve must occur very much nearer to the earth's external surface than to the interior surface of its crust; and the Author calculates that the maximum value of the geothermic scale, occurring at the point of inflexion, will be but very slightly greater than its mean value for the entire thickness of the earth's crust. The depth at which the mean value will be attained of the geothermic scale for the whole thickness of the earth's crust in the thinnest portions is probably not more than 3,000 mètres (10,000 feet). In Java, where the geothermic scale starts from the surface at about 12 mètres per 1° C. or 22 feet per 1° F., its mean value is calculated at 54 mètres per 1° C., and its maximum at 57 mètres, or 100 feet and 105 feet respectively per 1° F. At Yakutsk, with 7 mètres per 1° C. or 13 feet per 1° F. at starting, the mean value would be 155 mètres per 1° C. or 280 feet per 1° F.

Other general conclusions arrived at by the Author are, that the observed regular increase in the geothermic scale proves the earth to be in process of gradual cooling from a primæval uniformly heated state; but that, as the loss of heat from its surface, though incessant, is infinitely small in comparison with its store of central heat, a large portion of its interior mass must still remain at a very high temperature. Assuming 3,000° C. or 5,000° F. as the temperature of its fused or igneous core, the thickness of the crust in its thinnest or equatorial portion is probably not more than one-fortieth of the earth's radius, and in the thickest or polar portions three or four times as great, or even more. The thickness in any given latitude will also be greater beneath a deep ocean, owing to the mean temperature of the sea being lower than that of the land; thus the most sudden differences of thickness will occur under a latitude where, with a high mean temperature at the surface, the alternations of land and deep sea are the most frequent; and this view is in keeping with the mainly volcanic character of the islands in the equatorial archipelago. Local disturbances, such as volcanic eruptions, earthquakes, and geysers, as well as gradual up-

heaval or subsidence of tracts of land, cannot be more simply explained than by the reaction which the earth's solidified crust, of considerable thickness, and possessing low conductivity for heat, exerts upon its fused or igneous core.

A. B.

[NOTE.—Information on this subject will be found in the "Report of the Commissioners appointed to inquire into the several matters relating to Coal in the United Kingdom," vol. ii. p. 83 *et seq.*, London, 1871; also "Report of the Committee of the British Association on Underground Temperature"—Report of the Association, 1878, p. 178.—SEC. INST. C.E.]

Accidents in the Comstock Mines, and their relation to Deep Mining. By J. A. CHURCH.

(Transactions of the American Institute of Mining Engineers, May 1879.)

During the twenty-two months, July 1877 to May 1879, the number of accidents recorded was 101, proving immediately fatal to 53 persons, and 70 were wounded, the proportion of fatal cases being 43 per cent. This list is incomplete, since it takes note only of those accidents in which men were injured, and it does not distinguish those of the wounded who subsequently died. During this time from three thousand to three thousand five hundred men were employed above and below. Most of them worked eight hours, but some of those on the top worked twelve hours; probably there was a constant force of from nine hundred to one thousand men below. It is not possible to make a comparison of the accidents and the amount of ore raised, because most of the work during the twenty-two months was in dead ground. Only two out of about forty mines (the Consolidated Virginia and California) produced much ore during this time. At these mines, during 1878, the total number of accidents was ten, and the amount of ore raised 257,718 tons, or a proportion of 1 to 25,771 tons. The fatal casualties were 5, while 8 were not fatal.

Many accidents in the mines are due directly to the heated air, 73 per cent. under this heading being fatal; but many others are indirectly due to the same cause. The Author estimates that 12 per cent. of the casualties are directly, and 5 per cent. indirectly, due to hot air or water. The heat has a peculiar mental effect upon the men, and this is probably the cause of many mishaps, which under other circumstances would be ascribed to culpable blundering. Men often walk deliberately into winzes or shafts; others suddenly lose all power over themselves, or their memory fails completely; fainting when approaching the cooler air is of frequent occurrence; almost sudden death occasionally occurs. Very frequently the currents of hot gas are

rich in carbonic acid, and this may in part account for some of the effects observed. The hot water is very gaseous, and is therefore of low specific gravity, consequently men falling into it cannot readily recover themselves.

Accidents in the shaft are far more common on the Comstock than in other mines. Some of them, as already stated, are due to simple absent-mindedness on the part of the men, produced by the hot air. The shafts are all sunk in the hanging wall, and this wall, in consequence of the vast excavations in the mines, is constantly settling. But the rocks themselves are, from the heat and chemical action, always swelling and moving, and forcing the shafts out of the line, so that no shaft keeps long in good condition. All this entails constant work in the shaft, and partly accounts for the large proportion of shaft accidents.

From a review of the whole subject, the Author concludes that increasing heat alone will not prevent the Comstock mines from continuing to the greatest depths which for other reasons are practicable. But the heat, and other causes incident to deep mining, will probably increase about 40 per cent. of the accidents, and will leave 60 per cent. unaffected; the amount of this increase cannot yet be estimated. The administration of the mines is excellent, and the oversight ample; but "the managers seem to have come to the conclusion, which guides the framers of some European mining laws, that accidents will not cease until the damage is assessed on every one in the neighborhood of the casualty, innocent or guilty."

W. T.

Deep Mining on the Comstock.[1] By Prof. J. A. Church.

(Engineering and Mining Journal, New York, July 19, 1879.)

This was an address delivered to the Bullion Club, on Thursday, the 19th of June. The Comstock lode was discovered in 1858. During the last twenty years its yield is estimated at 6,500,000 tons of ore, of the total value of upwards of £75,000,000. The lode is developed along the course of an eruptive dyke, which ranges north and south, and hades to the east. Almost the whole of the ore has been found in rich masses (bonanzas), whilst the surrounding rock, for hundreds of feet in all directions along the dyke, is absolutely barren. There is no connection between one mass of ore and another; nothing by which future chances of success can be estimated when one bonanza is exhausted. The aggregate length of the workings is over 200 miles, increasing about 12 miles per year. The lode dips to the east, but

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[1] *Vide* "The Heat of the Comstock Mines," Minutes of Proceedings Inst. C.E. vol. lvii., p, 393.

not at an uniform angle; the more productive parts have a high dip—45° to 60°, whilst the barren parts are much flatter. There are four lines of shaft; one at the outcrop of the lode; one farther east, cutting the lode at 500 to 600 feet; a third line, now in use, cuts the lode at from 1,000 to 1,200 feet. The fourth line is in progress; this is from 2,500 to 4,400 feet east of the third line, and the shafts are expected to cut the lode at from 2,500 to 3,500 feet. Inclines will then be sunk along the dip of the lode, carrying the workings 1,000 feet deeper.

The future of the Comstock mines depends upon (1) the finding of fresh bonanzas at greater depths; (2) the control of drainage; (3) the possibility of work in the increasing heat of the rock. From 4,500,000 to 5,000,000 tons of water are now yearly pumped from the mine, and with increasing depth this quantity will be largely exceeded. But the Sutro tunnel will, in this particular, give the mines a new lease of life.[1] In many drifts the men often work in an atmosphere of 108° to 112° Fahr.; in the 2,000-feet level the temperature is 130°; whilst water of 156° Fahr. has found its way into one mine.

W. T.

On the Boring of the Coal Pit Deutscher Kaiser. By Hr. Reve.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, vol. xxvii., p. 67.)

In the western parts of the productive coal fields of Westphalia, where the sinking to be described is situate, the coal measures are overlain by thin strata of cretaceous marls covered by the alluvial deposits of the Rhine, here of considerable thickness. These geological conditions, which were well known from numerous borings, showed that any attempt to reach the coal would encounter considerable difficulties; an opinion which has been fully verified in the recently completed Rheinpreussen sinkings of Messrs. Haniel and Co.[2] The site of the pit is about 1¼ mile from the Rhine, the alluvial strata being 244 feet, and the cretaceous marls 176 feet in thickness. The work was commenced at the end of 1871, and the pit is now completed and drawing a considerable quantity of coal.

As a preliminary to the actual deep boring, a ring wall in masonry—built upon a wooden ring of triangular section, having a sharp edge faced with iron—of 21 feet 8 inches inside, and 25 feet 9 inches outside, diameter, was put down through the upper loose ground, of sand and gravel with erratic blocks, to a bed of blue clay, in order to obtain a foundation for the erection of the iron cylinders required in the deep sinking. The excavation was

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[1] This great work, which has been many years in progress, has just been completed.—W. T.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. lvii., p. 378.

effected by small sack or dredging borers. The cylinder sank regularly for the first 33 feet, when it stuck fast, and on the ground being excavated below the supposed impediment, went down irregularly on that side, and broke about 4 feet above the shoe, letting the ground in. This required the construction of a provisional system of timbering, to bear the weight of the boring machinery; when the wall was pulled down to the place of fracture, and the shoe lifted by levers, loaded with segments of tubbing, back to its proper place, after which it was built up again and sunk slowly, but without accident, to the clay at 52 feet, where a firm foundation was obtained by covering the shaft bottom with a bed of concrete 6 feet 6 inches thick. The boring was effected by a cylindrical iron cage suspended to a tubular rod of riveted wrought-iron plates 0·39 inch thick, and 12·5 inches diameter. The standard length of the rods between the couplings was 31 feet, but, for convenience, others of from 3 feet 3 inches to 9 feet 9 inches were occasionally used. The tubular construction was found to give a more rigid rod than the solid rectangular form hitherto used. The boring cage is 4·675 inches diameter, and revolves on a central spindle terminating in a double screw point at the bottom. The knives used are of three kinds; the first, or small fore-borers, of cast steel, 1 inch thick, and 5 inches breadth of face, cut a series of half-round channels in the bottom of the hole, the material being taken up by sacks of about 53 cubic feet capacity, attached to the boring frame. The second series of knives, of greater breadth, take off the ridges between the first series of cuts; while the third, or under-cutting knives, which are attached to spring beams, cut out the sides of the hole to the full size required for the descent of the tubbing. In lowering, these spring beams are drawn in by a capstan rope, to allow the boring frame to pass freely through the tubbing; and when this is let go they are pressed outwards by the springs, into the working position. In strata containing nodules of pyrites, cast steel forks were used in the advance boring, to loosen the nodules from the adherent marls. The concrete bed not having consolidated sufficiently after three months' rest, the shaft within the brickwork was filled up for 26 feet with clay and sand, upon which the sinking crib of the tubbing was erected. This is a ring, 3 feet 1 inch high, and 17 feet inside diameter, divided into twelve segments; the tubbing rings are of the same height, but only 15 feet 5 inches inside diameter. The borer was then set to work, and the tubbing went down, more or less regularly, to a depth of 129 feet, when the resistance of the ground became so great that the borer could be no longer rotated. As the nature of the ground, blue sandy clay of a very loose texture, did not allow the water to be pumped out, divers were employed, who discovered that the bottom ring of the tubbing was displaced over about one-third of the circumference and driven into the shaft. In order to repair the damage, the bolts connecting the various segments were unscrewed and after various attempts had been made to pull them

out by a capstan rope, one of the segments, 2 inches in thickness, was, at the fifth trial, broken into several pieces by a charge of dynamite, of about 1 lb., exploded upon it by one of the divers. This released the pressure so that the remaining segments could be easily removed. A fresh bed was then bored out, and new segments were placed by the skilful exertion of the divers, the work being done under 4 atmospheres pressure. After this the work proceeded mainly through sands with nodules of pyrites, often giving considerable trouble, down to 192 feet, when another segment of the bottom ring broke, and protruded into the shaft. This was fished out by claw hooks; but as the depth was too great to permit of another attempt at replacing the broken piece by divers, the pressure being 5½ atmospheres, it became necessary to continue the sinking with a new iron shaft of smaller dimensions, 13 feet 4 inches internal diameter. The bottom ring of this was cast in a single piece, and the following ones in ten segments, a provisional foundation being made, as in the first instance, by filling up the original shaft for about two-thirds of its depth with sand and clay which was afterwards bored through in the usual way. When the point where the first tubbing failed was reached, eight levers, each exerting a pressure of 30 tons upon the top of the iron cylinder, were used to force it down against the resistance of the ground. Subsequently, the ground became much harder; and at 248 feet, in hard marl with stone nodules, it was no longer possible to excavate it by rotatory cutters alone. Here, therefore, the boring was stopped and the further sinking was conducted in the ordinary way. As a preliminary to the latter, however, the cylinder, which had stopped in its descent about 6 feet 6 inches short of the bottom, was pressed home by a combination of levers and jack screws, aided by a current of water set up by pumping from the inside of the shaft into the clearance space between it and the outer ring wall.

The first boring was completed, down to the point where it was abandoned, in four months; and the second, down to the water-tight stratum, in five months. Five months were required in making preparations for the first; for the second, including that necessary for completing the sinking to the top of the coal measures, about six months more. The first coal seam, 5 feet 3 inches, was reached about 16 feet greater depth, or at 427 feet, at the end of 1874.

The successful completion of this sinking in the short period of twenty months is attributed by the Author mainly to the novel idea of using oxen for rotating the borer, which is done by two cross arms, like those of a whim attached to the head of the rod. Oxen have this advantage, that when the resistance is sufficient to stop the rotation they do not stop or back like horses, but continue pulling; and therefore all backward motion, which is very destructive to the apparatus, is prevented. It is also easier to find out the position of nodules of stone or other impediments in the shaft, as the rod is perfectly rigid, and as the

motive power employed is only capable of a limited effort, the boring gear is less liable to be strained or broken than when it is rotated by steam power.

The completed shaft is lined with cast-iron tubbing down to 26 feet 3 inches below the top of the coal measures. The total weight on the two cylinders—

	Tons.
In the first sinking (abandoned at 192 feet) . . .	304·38
In the second sinking, 450 feet deep	694·3

The sinking crib of the latter, cast in a single piece, weighs 62 cwt. H. B.

On an Instrument for Determining the Inclination of Bore Holes.

By Hr. SELBACH.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, vol. xxvii., p. 176.)

This instrument, invented by Herr G. Nolten, a magistrate at Dortmund, measures the deviation of a bore hole from the vertical line, by the corresponding variation from the horizontal plane of the free surface of a fluid in a suspended cylinder. For this purpose a vertical glass cylinder, filled to about half its height with a mixture of one part of hydrofluoric acid[1] and four of water, is attached to the boring rod or capstan rope, lowered to the required depth, and allowed to remain at rest for half an hour, when it is drawn up again. During the lifting and lowering, which are quickly done, the fluid is in a state of irregular movement, and therefore the corrosive fluid has only a slight and diffused effect on the glass; but during the period of repose, a ring exactly corresponding to the contact of the upper surface of the fluid, is sharply etched into the glass cylinder to about one-tenth of its thickness. By removing a portion of the solution, and either suspending the vessel at the end of a plumb line or placing it upon a true horizontal surface for a second period of similar length, a second ring is formed, giving the position of the horizontal datum plane; and by measuring the difference in distance between the two the inclination of the first to the second, and from it that of the axis of the tube in the two positions, is easily found.

A method of determining the direction of the inclination by compass has also been devised by the inventor. This is done by attaching a small pocket-size compass with a light needle to the rod, which is allowed to swing freely on its centre during the descent, and for some time afterwards, when it is stopped by a lever, worked by a watch movement, releasing a catch at some period previously arranged, and which, in the instrument first made, may be from $\frac{1}{4}$ to $\frac{3}{4}$ hour. The needle, when brought back to the surface,

[1] The strong aqueous solution of the acid used in chemical laboratories.

will then be found indicating the particular azimuth in which it was swinging at the moment the catch was released.

The Author gives the results of experiments made jointly with the inventor upon lines of tubes of known inclination, as well as upon actual bore holes. The azimuth observations, as a rule, were unsatisfactory, especially in cases where sheet-iron lining tubes were used. No single observation could be relied upon to give even an approximate direction of the deviation from the magnetic meridian. As regards inclination, however, they were more satisfactory; the inclination of two tubes known to be 80° 10′ being given, in the most favourable observations, at 81° 2′.

A more accurate method of determining the difference in distance between the two rings than direct observation, is to take a plaster cast of the interior of the glass tube, and use a two- or three-fold photographic enlargement of this for measurement by a cathetometer. The deepest boring that has been tested is that at Lieth, in Holstein, where the instrument was applied by Herr Köbrich, with the following results:—

1. From the surface to 110 yards the bore hole was vertical.
2. At 218 yards a slight deviation is perceptible; and at 328 yards it amounts to 3°.
3. At 546 yards another slight deviation commences, which at 874 yards is about 1°, and continues the same to 1,093 yards.

Two observations gave the direction of the deviation at 546 yards, as north-north-east, and at 765 yards as west; but these results are regarded as uncertain, owing to the small angular deviation from the vertical.

As regards packing material for the different joints of the instrument, it was found that indiarubber, whether hard or soft, could not be relied upon to keep out water below 437 yards; but that varnished paper joints were perfectly tight under a pressure of 1,093 yards.

The diameter of the first instrument is rather more than 3 inches, so that it cannot be used in holes below 4 inches diameter; but a smaller size, 2·24 inches in diameter, has been constructed for use in 3-inch holes. H. B.

The Bilbao Iron Mines.[1] By M. Bailles.

(Annales des Mines, vol. xv., 1879, p. 209.)

The Author gives descriptions and analyses of the three principal varieties of Bilbao ore—the campanil, vera dulce, and rubio, and remarks that the deposits probably consisted originally of nearly homogeneous masses of carbonate of iron, interposed between beds of schistous grit below, and of limestone above, both of middle cretaceous age; and that the varying character of the ores now

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lvii., p. 384.

found appears to be due to the greater or less extent to which they have been weathered. Thus the deepest ore, now the vera dulce, is the least altered; that immediately under the limestone, the campanil, is more weathered; and that cropping out on the surface is the rubio, which contains the greatest proportions of water and of impurity. These typical varieties pass insensibly, throughout the deposit, one into another.

The experience of wire-rope tramways, at the Bilbao mines, has not been favourable; they are costly to maintain, and are liable to be interrupted by breakages of the rope, so that inclined planes and ordinary railways, though more expensive, are on the whole preferred.

Some particulars are given at the end of the Paper of the treatment of the softer ore (vera dulce) by the Chenot process, at the El Desierto works, near Baracaldo. Each reducing furnace, used there for making spongy metallic iron from the ore, consists of two vertical brick retorts, 4 feet 7 inches by 1 foot in section, and 28 feet high. The retorts are heated externally by coal fires, and each of them is prolonged below by a sheet-iron cooler, 8 feet 1½ inch high. They are charged with ore and charcoal in alternate layers. The operation is carried on continuously, a portion of the reduced sponge being withdrawn at the bottom of the retort twice a day, and fresh ore and charcoal filled in at the top. The reduction of the ore and the cooling of the sponge require three days, and each retort thus yields about 0·72 ton of sponge every twenty-four hours, with a consumption of 1·27 ton of ore, 0·24 ton of charcoal, and 0·46 ton of coal. The cost per ton of the sponge is about equal to that of pig iron made at the same works. The sponge is made into balls of forgeable metal in charcoal hearths, worked with blast at a pressure of 1·18 inch of mercury. Each hearth works in twelve hours fifteen to twenty charges, consisting each of 202 lbs. of sponge and 55 lbs. of charcoal. The cinder produced is very rich in iron; and 1·86 ton of sponge and 0·5 ton of charcoal are consumed per ton of bar made. The metal is very soft and malleable, and is specially used for nails for shoeing oxen.

The process seems likely, however, soon to be given up: it requires a very pure and a very rich ore, and the management of the operation is difficult. In working the sponge also into balls, the consumption of it is enormous. At the El Desierto works the number of furnaces in operation has been gradually reduced from six to two. W. H.

The Dephosphoration of Iron. By Dr. K. List.

(Zeitschrift des Vereines Deutscher Ingenieure, 1879, p. 267.)

Dr. List's essay is an historical sketch of the attempts made to remove phosphorus from pig iron. He starts with the experiments of twenty years ago, and brings a very complete review of his

subject down to the recent methods of Thomas, Gilchrist, and Snelus. He first notices briefly some of the wet processes which have been tried, with the object of freeing the ore from phosphorus, before smelting has been begun; treating then at considerable length the various processes, whether proposed, patented, or carried out, for removing the phosphorus during the process of reduction or after the metal has been reduced. The Author has dealt with this extensive subject so concisely that an epitome of the Paper would be little more than a list of names. It is not, therefore, attempted to abstract it, but simply to indicate its existence as a memoir which will be found of considerable value to any one requiring historical information upon the subject.

A. B. W. K.

Magnetic Impenetrability of Iron. By J. Jamin.

(Comptes rendus de l'Académie des Sciences, vol. lxxviii., p. 1100.)

The Author recurs to the contested question as to the impossibility of causing magnetism to penetrate to considerable depths in iron and steel, and presents a series of experiments that he believes to offer a solution. There are placed, one above another, two equal bobbins wound with thick copper wire, separated by a third bobbin of fine wire which is connected to a reflecting galvanometer. A current in the two primary coils induces a current in the third, the secondary coil. The arc shown by the galvanometer is recorded as a. There is then introduced into the three bobbins an iron tube $\frac{1}{8}$ of an inch thick. The primary current now induces a stronger secondary current, A; $A - a$ measures the magnetisation of the iron tube. Instead of the tube, a bar of iron equal in height is introduced, and the deflection A′ obtained. The bar is then placed in the interior of the tube, and a deflection A″ obtained. The following are one series of numbers:—

$A - a$	49·5
$A' - a$	48·5
$A'' - a$	54·0

$A'' - a$ was then obtained with the tube and bar placed side by side = 59·5.

The Author considers these and other experiments he details to prove that the same current communicates to the bar much less magnetism when the bar is contained in the tube than when it is exterior to it, and that the tube takes greater magnetism in the first case than in the second. And he definitively asserts that $\frac{1}{4}$ inch concentric depth of iron completely arrests the magnetic effect of an external spiral.

P. H.

On some curious Phenomena observed in making a Test of a Piece of Bessemer Steel. By W. KENT.

(Transactions of the American Institute of Mining Engineers, May 1879.)

The test piece contained 0·34 per cent. of carbon; it was turned to a sectional area of 1 square inch, and was 5 inches long between the shoulders. The testing machine was fitted with a special apparatus, containing two micrometer screws and an electric contact apparatus, enabling elongations to be read accurately to $\frac{1}{10000}$ of an inch. After being tested to 45,000 lbs. tensile strain, the modulus of elasticity fell from 25,000,000 lbs. to 22,500,000 lbs.; this was supposed to point to some internal flaw.

On removal from the machine, an accidental delay of ten days took place before the tests were recommenced, when the modulus of elasticity was found to have risen again to 25,352,000 lbs., or more than it was at first. The piece finally broke with 75,000 lbs. pull; and, on examination, a rupture, or appearance of flaw, about $\frac{3}{8}$ inch in diameter, was found in the centre of the fracture.

The Paper is accompanied by a diagram, on which the strains and the corresponding elongations are plotted.

W. P.

A New Circular Roasting Furnace. By W. M. BRODIE.

(Engineering and Mining Journal, March 15, 1879, p. 181.)

The furnace described in this note, and illustrated by several woodcuts, was put up by the Author at works near Alamos, Mexico. It is built round the chimney, in the form of a ring, the fire-grate and the opening to the chimney flue being close together, separated only by a brick partition. The principal advantage of this construction is the strong and simple way in which the furnace may be bound. No buckstaff, tie rod, or nut is required. A ring of ordinary flat bar iron, which encompasses the whole, and is placed at the height of the springing of the arch, before this is built, binds all together most effectually. To keep the flame from following too much the shortest course to the chimney flue, round the inner or chimney side of the bed, the springing of the arch is made lower on this than on the outer side. The furnace takes up little space, compared with others of the same length of bed, and is cheaply constructed. Six working doors, for stirring the charge, are arranged at intervals round its outer wall, and, owing to the annular form of the bed, the rabbles have easy access to every part of it.

W. H.

Notes on Zinc Smelting. By F. A. Thum.

(Engineering and Mining Journal, April 19, 1879, p. 275.)

The present annual output of zinc amounts to 150,000 tons, of which fully 75 per cent. is produced in Belgium and North Germany.

The loss of the metal in distillation is 20 to 25 per cent. of the quantity contained in the ore; an excessive amount, that may be reduced, it is to be hoped, by improved modes of working and greater care.

The width of both Belgian and Silesian retorts found best in practice is 6½ inches inside. With this width, the charge in the cylindrical Belgian retort is exhausted in twelve hours, and in the Silesian retort in twenty-four hours.

The Author thinks it likely that the Belgian form of furnace, with small cylindrical retorts, suspended in an inclined position over the fire, and supported at the ends only, will before long become extinct. The retorts and furnaces are small, and cannot be satisfactorily enlarged, and they have many other disadvantages. A good point, however, in the Belgian mode of charging is that the charge is generally rammed tightly into the retort, instead of being merely thrown in, as it is on the Silesian system. The interspaces in the charge are thus kept smaller, and retain proportionately less zinc vapour, which is lost when the charge is drawn.

While Belgian retorts, 6½ inches in diameter, can hardly be made more than 3½ feet long, the muffles used in Silesian furnaces, resting throughout their length on solid supports, are 6 to 7 feet long, and above 2 feet high. Their size and the number placed in each furnace have been very much increased of late years, the charge of ore per furnace having been raised from 14 or 16 cwt. to as much as 6 tons, and the consumption of coal reduced to nearly an equal weight to that of the ore charged, against three or four times that quantity in former days.

Gas heating has been successfully applied to Silesian zinc furnaces, and has done much to encourage the increase in their size; the durability of the largest furnaces, heated by gas, being much greater than that of the small coal furnaces ever was.

The Author reviews briefly the Siemens, Boëtius, Bicheroux, Ponsard, and Pütsch systems of gas furnace, as applied to zinc smelting, and pronounces the Siemens furnace to be in every way the best. W. H.

The Desilverising Works at Newark, New Jersey. By Hr. Koch.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, vol. xxvii., p. 171.)

The greater part of the ore-furnace lead smelted in the States of Nevada, Utah, and Colorado, is sent to refineries on the Pacific side,

or in the Eastern States, where it is desilverised, and softened for market. The most important of these establishments is Balbach's Smelting and Refining Works, at Newark, in New Jersey, having a branch at Omaha, in Nebraska. These were originally designed for desilvering only, but the smelting of ores has been added, although it forms but a small part of the actual work done. At Newark there are two cupola furnaces, about 30 feet high, with water-cooled iron-jacketed hearths, for ore smelting, which are also used for working up residual products, with the addition, when possible, of dry earthy silver ores.

The furnace lead, the treatment of which is the principal business of the works, is mostly very impure, and requires a preliminary calcination in the improving furnace, to remove a certain quantity of antimonial dross. The softened lead, containing from 0·3 to 1 per cent. of silver, is remelted in a reverberatory furnace, with an inclined bed made of cast-iron plates, and run into pots, where it is treated with zinc. The quantity of the latter metal is so proportioned that the skimmings, after distillation, may leave a residual rich lead, with 8 or 10 per cent. of silver. The actual quantity of zinc used is, on account of the highly argentiferous character of the lead, larger than in German works, amounting to between 1½ and 3 per cent. of the weight of lead treated.

When the zinc is considered to be of the required richness in silver, it is drawn in a coherent crust from the lead bath by chilling the surface with water, and returned to the reverberatory furnace for liquation. This process is conducted at such a temperature that only the adherent lead is melted, the more refractory zinc and silver alloy being only softened. Care is taken to exclude air as completely as possible, to prevent the formation of metallic oxides. The lead separated is nearly free from silver, runs down the inclined furnace bed back to the desilverising pots, and the argentiferous residue, containing only 4 to 6 per cent. of lead, is mainly in the metallic condition, which is a point of considerable importance in facilitating its subsequent treatment by distillation.

The furnace used for the latter operation, the joint invention of Messrs. Balbach and Faber du Four, is an air furnace mounted upon trunnions, and turning about a central axis by screw-wheel gearing. An arch formed above the fire grate forms a support for a single bottle-shaped retort, inclining upwards, the neck of which projects through the front wall. The retorts, made of black lead, fire clay, and burnt brick, are 2 feet 7 inches high, 2¾ inches thick, and cost from 14 to 16 dollars each. The charge—consisting of 220 to 330 lbs. of the dry zinc skimmings, which are broken up on an iron plate in front of the reverberatory furnace bed—introduced while still red hot, with from 4½ to 9 lbs. of charcoal dust, into the retort, also at a red heat, is fired for eight or ten hours at the full temperature of the furnace, about 880 lbs. of coke being burnt during that time. The zinc separated is condensed in a receiver, usually formed of the neck of an old retort, to the extent of about 40 per cent. as fluid metal, and 20 per cent. in the

forms of metallic dust and oxide, all of which are practically free from silver. The residual rich lead, containing only traces of zinc, is removed by turning the furnace on its axis until the neck of the furnace is below the horizontal position, when it runs into a mould placed for its reception, and is fit for immediate refining on the test. The yield of silver is about 98 per cent. of that indicated by assay. The retorts bear from fifteen to thirty charges without renewal, and their life may be lengthened by the use of gas firing, which has been tried to some extent.

The process described differs from that of Cordurié, followed at Lautenthal, and that of Friedrichshütte, in Tarnowitz, by the care taken to prevent the oxidation of the zinc during the process of liquation, so that the unsatisfactory operation of reducing large quantities of argentiferous zinc oxide is entirely avoided. A similar method is now followed at the Mechernich Works, where it is said to give satisfactory results.

The desilverised lead is subsequently treated in the reverberatory furnace, to remove the last traces of zinc and prepare it for market. All dross and other products containing copper are collected and melted, with the addition of sulphuretted copper ore, fluor spar, and lime, in the blast furnaces for lead and copper regulus, which latter, by the ordinary calcination and reverberatory furnace processes, is concentrated into rich regulus and argentiferous copper bottoms. These, when granulated, are roasted in quantities of 6 cwt. for twelve hours, the charge being turned every five minutes, and the oxidised product is dissolved in sulphuric acid. About 3 tons of blue vitriol are made weekly. The residual silver contains gold, and is parted by sulphuric acid in iron pots. The daily production of the works is about 60 tons of soft lead, nearly sixty hands being employed.

The process described is adopted at most of the lead refining works in the United States, under the name of Balbach process.

H. B.

Underground Pumping Engine at the Arnim Coal Pits at Planitz. By B. Otto.

(Zeitschrift des Vereines Deutscher Ingenieure, 1879, p. 211.)

The Author describes in great detail, with the help of a number of illustrations, the general arrangement of the pumping plant, as well as the details of construction of the engine, pumps, and valves themselves. The engine is horizontal, having one cylinder, 1 feet 3½ inches diameter and 2 feet 3½ inches stroke, working two single-acting plunger pumps, each 6·9 inches diameter, direct from the prolongation of the piston rod. The front end of the piston rod drives a heavy shaft, carrying a fly wheel weighing about 7 tons. The engine has been designed to pump 220 gallons per minute 650 feet high when working with a boiler pressure of 75 lbs. per square inch, and having a piston speed of 175 feet per minute. It was made at the Sächsische Maschinenfabrik, in

Chemnitz, and takes the place of an old 200-HP. single-acting high-pressure non-expansive beam engine, made by the same firm eighteen years since, and now kept as a stand-by. The cost of excavating the engine house, and that of the masonry in the engine room and its communications, is given as £380, against which is placed £272, the value of the coal removed. The cost of the engine itself was £750, of the delivery pipes £227, of the steam pipes £180 (not including fixing). The whole cost (the details are given) of the plant was about £1,400, its weight being about 31 tons.

A. B. W. K.

Air Compressor with Water Pistons. By P. Hanrez.

(Revue universelle des Mines, 1879, vol. v., p. 139.)

This is a horizontal double-acting air-compressor, with vertical water pistons, of the type of Sommeiller's [1] and Low's [2] machines, designed by the Author to obviate the one objection commonly appertaining to air compressors of that class—namely, the low speed at which they have to be worked, in consequence, as has generally been supposed, of the large mass of water to be put in motion at each stroke. The real reason, however for the speed having to be so limited has, in his opinion, been the neglect of certain special conditions necessary to be observed. The water column in the upright chamber at each end of the horizontal cylinder, in order to act to the best advantage as the air-compressing piston, ought to retain a level surface, so as to touch the cover throughout its whole extent at the top of its stroke, leaving no clearance space to occasion loss; instead of which, at even a moderate speed of working, the surface ordinarily becomes violently agitated, and the useful effect is poor. Moreover, the inlet and delivery air-valves, when sometimes placed within the extent of vertical travel of the water, disturb its steady movement, interrupting what ought to be the uniform sectional area of the column of water.

In the Author's air-compressor the speed of the vertical water columns is reduced to half that of the working piston, by making the sectional area of each upright water chamber double that of the horizontal cylinder; and the junctions of the cylinder with the chambers are so arranged as to render the enlargement of area gradual, avoiding any sudden change either of area or of direction. The air valves are all placed in the covers on the top of the

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiii., p. 280.

[2] *Vide* Proceedings Institution of Mechanical Engineers, 1865, p. 186. In Low's air-compressor working the rock-boring machine at the Roundwood tunnel of the Dublin Corporation waterworks, the horizontal cylinder was 14 inches diameter with 18 inches stroke, and the speed was 22 revolutions per minute, giving 66 feet per minute for the piston, and the same speed for the water columns in the upright chambers of equal sectional area.—A. B.

ıpright chambers, and are arranged so as to leave the least ɔossible clearance space. Metal mushroom-valves being generally ound to get out of order soon and leak, flap-valves of leather or ndiarubber are here employed by preference. The delivery flap ralve beats on a horizontal grid in the centre of the cover, and ıach side is an inlet flap beating on a nearly vertical grid; all the ralves give large openings for the passage of the air. The water equired for keeping the chambers cool is admitted through the nlet air-valves.

Several of these air-compressors are now in use, with cylinders f 24 inches diameter and 40 inches stroke. They work with great egularity, and without any shock, at a speed of 30 revolutions ɔer minute, which can be exceeded without inconvenience. This ;ives a horizontal-piston speed of 200 feet per minute, while the urface speed of the water columns in the upright chambers is only ıalf as much, or 100 feet per minute. The results are excellent, wing to the almost entire absence of clearance spaces, and the voidance of leakage past the piston. The maintenance is merely ıominal, and the useful effect, the Author considers, must be uperior to that realised by other plans, especially after some time f working, when the pistons begin to get worn.

A. B.

The Lorimier Man-Engine. By F. Goebel.

(Revue universelle des Mines, 1879, vol. v., p. 130.)

The mechanical contrivances employed for lowering and raising ıiners consist either of cages worked by ropes or of man-engines. The use of cages worked by the ordinary winding engine obviates he need of a separate shaft for the men; or, if a separate shaft is rovided for them and the cages are worked by a special engine, his shaft and engine can also be used for sending down materials, ɔc., without interfering with the working of the regular winding ngine, which, on an emergency, can thus be supplemented. But here is always risk of accident by breakage of the ropes, however arefully they are looked after, and in spite of the provision of afety-catches upon the cages. With man-engines, on the contrary, he men's lives are in their own hands, their safety not being ndangered even by breakage of the machine; and a given umber of men can be lowered or raised in a much shorter time han by ropes, the advantage in this respect increasing with the epth.

In the first man-engines introduced in Belgium, the power was pplied direct to the vertical rods; and in those known as "Wa-ɔcquères"—from having been erected in 1845 at the Mariemont nd Bascoup collieries, near Charleroi,[1] by the late principal owner,

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[1] *Vide* 'Transactions of the North of England Institute of Mining Engineers,' ɔl. xxvii., 1877–78, pp. 181 and 183; and 'Revue universelle des Mines,' 1877, ɔl. i., pp. 156 and 158.

M. Warocqué—the connection between the two rods, for ensuring their moving always in contrary directions to each other, is a water balance; while at Seraing an arrangement of pulleys is used instead. The application of crank shaft and fly wheel for controlling the motion was a great step in advance, giving a maximum speed of considerable amount in the middle of each stroke, with a reduction of speed towards the end; in consequence of which a much higher average speed can be attained, together with a saving of fuel estimated to amount to 75 per cent. in an engine working expansively with cut-off gear controlled by the governor, as in M. Guinotte's man-engine.[1] From eight single strokes per minute, of 10 feet length, the speed has thus been increased to ten of 12½ feet,[2] or from 80 to 125 feet per minute; while ten strokes of 16½ feet, being 165 feet per minute, or more than double the first speed, have been attained by M. Guinotte, by the adoption of hydraulic transmission of the power, and by the further device of making the steps or platforms on the two rods over-run one another slightly at each end of the stroke, so as to allow rather more time for the men to step across from one rod to the other. But in all machines worked by a crank motion, and where the opportunity for stepping from one rod to the other is only that afforded by the lower speed at the time of the crank passing its dead point, the average speed of the stroke has to be kept down within such safe limits, as that the reversal of motion at each end of the stroke shall not be too sudden for the men to step across without risk.

The entirely novel feature in the man-engine designed by M. R. Lorimier, engineer of the Mariemont and Bascoup collieries, consists in ensuring an absolute pause of definite duration at each end of every stroke of the rods, while still retaining the full advantages attendant upon the use of a crank motion for driving the rods and upon hydraulic transmission of the power. By the adoption of this principle, superseding the previous momentary stop of no actual duration, a still higher speed of working can be attained, in combination with absolute safety for the men.

The pair of vertical rods or spears of the man-engine are suspended from the rams of a pair of single-acting vertical hydraulic cylinders at the pit mouth, one for each rod; and to these cylinders the power is transmitted from a pair of double-acting horizontal hydraulic cylinders[3] or piston-pumps of equal volume, of which

[1] *Vide* 'Revue universelle des Mines,' 1877, vol. i., p. 166.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xlvi., p. 340.

[3] In M. Lorimier's apparatus, shown last year at the Paris Exhibition, each of these double-acting horizontal cylinders fitted with a piston is replaced by a pair of single-acting plunger-pumps, placed in line and face to face, and worked by a plunger common to both, which makes its instroke in one simultaneously with its outstroke in the other. A steam cylinder fixed in line with the pump-plunger works direct upon one of the cranks on the fly-wheel shaft; and from the piston-rod crosshead the pump-plunger is driven by a pair of side-rods attached to the middle of its length. For convenience of description however, M. Goebel's representation of the pumps has here been followed, each being regarded as a double-acting cylinder with piston.—A. B.

nly one at a time is effective in working. While water is being orced into either one of the vertical cylinders, the same quantity s simultaneously being withdrawn from the other; and thus while ne rod is ascending the other is descending at the same rate, and he movements are alternated by the forward and backward strokes f one or other of the pumps. These latter are worked by cranks eyed at right angles, instead of opposite to each other, upon a fly-wheel shaft driven by the steam engine. Each pump alternately is aused to be effective throughout a single stroke, commencing and erminating at the dead points of its crank; and the half stroke, ntervening between the dead points of one crank and those of the ther at right angles to it, forms the interval taken advantage of y M. Lorimier for the period of absolute rest, which constitutes he novel principle of his man-engine.

The way in which the arrangement is carried out is by having wo valve-chests on each horizontal cylinder or piston-pump, one t each side; with two stop-valves in each chest, one at each end; naking four valves to each pump, and eight valves for the pair. The valve-chest on one side of each pump communicates with the irst of the vertical man-engine cylinders; while the second vertical ylinder is in communication with the opposite valve-chests. If oth of the stop-valves in any one of the valve-chests be opened ogether, the working of that pump is rendered ineffective, the vater being merely driven round from one face of the piston to he other. Suppose this to be the case with the left-hand pump, vhile in the right-hand pump the piston is at the commencement f its forward stroke, with the front valve open on one side of the ump, and the back valve on the other side—that is, two diago-ally opposite valves are open, and the other two diagonally pposite are shut—then by the stroke of the right-hand piston he water is forced into one of the vertical man-engine cylinders, nd withdrawn from the other, causing one rod to make its pstroke, and the other its downstroke simultaneously; and the notion of each rod throughout the stroke is the same as if the ods were worked direct from a pair of opposite cranks on the fly-wheel shaft. At the end of the forward stroke in the right-hand ump, this pump is rendered ineffective by opening one of its ther two valves hitherto closed, the opposite valve hitherto open t the same end being simultaneously closed; and the left-hand iston, being at that moment in the middle of its stroke, is still ept ineffective through its remaining half stroke, during which eriod therefore the man-engine rods remain at rest, one at the op and the other at the bottom of its stroke. On the left-hand iston reaching the end of its ineffective stroke, it is then rendered ffective by opening two of its diagonally opposite valves, and losing its other two diagonally opposite, so as to establish the roper communications with the vertical man-engine cylinders for mparting the reverse movement to each of the two rods.

By the rotation of the fly wheel or driving shaft therefore, the nan-engine rods are caused to make their stroke during half a

revolution, and then to remain at rest during the succeeding quarter of a revolution. The driving shaft thus runs alternately loaded through half a revolution, and empty through a quarter; while the two piston-pumps are each in turn effective through a single stroke or half revolution, and ineffective through a double stroke or whole revolution, with an ineffective interval of a half stroke or quarter revolution between the effective stroke of one piston and the succeeding effective stroke of the other piston. The entire cycle of movements occupies three revolutions of the driving shaft. The arrangement adopted for working the stop-valves enables the man-engine rods to be stopped at any moment in case of accident, without stopping the driving shaft. Safety valves are provided upon the two horizontal cylinders or pumps; and the water lost through these and through the stuffing-boxes is made up by a small pump.

With 6 mètres (19·68 feet) length of stroke for the man-engine rods, M. Lorimier considers the period of each stroke and pause can by this machine be reduced without difficulty to 4 seconds, corresponding with 11½ revolutions per minute of the driving shaft; this gives 1½ mètre (4·92 feet) per second as the average speed of the rods, including the stoppages, or 295 feet per minute, which is from twice to more than three times the speed obtained in man-engines worked by direct connection or gearing from the driving shaft. The effect of alternately throwing the load on and off the engine he believes will be to apportion the period of 4 seconds into 3 seconds for the effective or loaded half-revolution, and 1 second for the ineffective quarter-revolution during which the engine runs light while the rods remain stationary: instead of the 2⅔ and 1⅓ seconds respectively, which would result from a uniform speed of rotation. The time of 3 seconds for the loaded half-revolution corresponds with what would be 10 revolutions per minute of a shaft driving the rods direct by opposite cranks in the ordinary way, without any intervals of pause. The average speed of 1½ mètre per second, including the stoppages, would enable a man to ascend or descend to a depth of 300 mètres (328 yards) in 3½ minutes, and to 1,000 mètres (1,094 yards) in about 11 minutes. With steps or platforms fixed 12 mètres (39·37 feet) apart on the rods, that is, at double the length of stroke, and allowing the men to travel in pairs, four hundred men could then ascend or descend through 300 mètres in less than 30 minutes, and through 1,000 mètres in less than 38 minutes. With a pair of ropes and cages, and allowing sixteen men per cage, and a mean running speed of 6 mètres per second (1,180 feet per minute), with one minute's interval between each run, the same operation would occupy more than ¾ hour and 1½ hour respectively.

The advantages offered by the Lorimier man-engine are accordingly—complete safety for the men, in consequence of the pause of definite duration produced automatically and with perfect regularity; high speed of working, and rapid conveyance of the men; facility for stopping the working of the rods in case of accident;

economy of fuel, resulting from expansion and from the use of a fly wheel; and fewer platforms on the rods, with consequently less total mass in motion.

A. B.

Maximum Electrical Work. By M. Gessé.

(La Lumière Electrique, vol. i., p. 31.)

The Author selects, from the report of the Society of Sciences of Cherbourg, the following formulæ, intended to be a methodical guide in the choice of relation between electromotor elements and resistances worked, with regard to the electro-mechanical work recovered. n is the number of electromotor elements; E R, electromotive force and internal resistance of an element; a, number of elements in tension; r, external resistance besides that worked; ρ, resistance of each of the resistances worked; t, resistance to earth. Employing B. A. units (volt, weber, ohm), the coefficient K represents 0·0002405 calories and 0·10192 kilogrammètre.

The case is first taken of a single circuit and a single resistance to earth, after an external resistance r.

Remarks.	Value of each of the Resistances Worked.	Seriation of Electromotor Elements.	Mechanical Work Developed per Second in each Resistance Worked.
Resistance and seriation given, arrangement in tension. (1) .	$\rho = \rho$	$a = n$	$\dfrac{K E^2 \rho}{\left(R + \dfrac{r+\rho+t}{n}\right)^2}$
Ditto, characteristic, different from n. (2) .	$\rho = \rho$	$a = a$	$\dfrac{K E^2 \rho}{\left(\dfrac{a R}{n} + \dfrac{r+\rho+t}{a}\right)^2}$
Resistance given, to find the seriation giving maximum mechanical work. (3)	$\rho = \rho$	$a = \sqrt{\dfrac{n}{R}(r+\rho+t)}$	$\dfrac{K E^2 \rho}{\dfrac{4R}{n}(r+\rho+t)}$
Seriation given, to find the resistance, &c. (4)	$\rho = \dfrac{a^2}{n} R + r + t$	$a = a$	$\dfrac{K E^2}{4\left(\dfrac{R}{n} + \dfrac{r+t}{a^2}\right)}$
To find both seriation and resistance giving, &c. (5)	$\rho = n R + r + t$	$a = n$	$\dfrac{K E^2}{4\left(\dfrac{R}{n} + \dfrac{r+t}{n^2}\right)}$

A single circuit, and M derived resistances to earth, after an external resistance r.

Remarks, same as	Value of each of the Resistances Worked.	Seriation of Electromotor Elements.	Mechanical Work Developed per Second in each Resistance Worked.
(1) .	$\rho = \rho$	$a = n$	$\dfrac{K E^2 \rho}{M^2 \left(R + \dfrac{r + \frac{\rho}{M} + t}{n} \right)^2}$
(2) .	$\rho = \rho$	$a = a$	$\dfrac{K E^2 \rho}{M^2 \left(\dfrac{a R}{n} + \dfrac{r + \frac{\rho}{M} + t}{a} \right)^2}$
(3) .	$\rho = \rho$	$a = \sqrt{\dfrac{n}{R}\left(r + \dfrac{\rho}{M} + t\right)}$	$\dfrac{K E^2 \rho}{\dfrac{4 M^2 R}{n}\left(r + \dfrac{\rho}{M} + t\right)}$
(4) .	$\rho = M\left(\dfrac{a^2}{n} R + r + t\right)$	$a = a$	$\dfrac{K E^2}{4 M \left(\dfrac{R}{n} + \dfrac{r + t}{a^2}\right)}$
(5) .	$\rho = M (n R + r + t)$	$a = n$	$\dfrac{K E^2}{4 M \left(\dfrac{R}{n} + \dfrac{r + t}{n^2}\right)}$

N circuits, each comprehending M derived resistances to earth, after the external resistances r.

Remarks, same as	Value of each of the Resistances Worked.	Seriation of Electromotor Elements.	Mechanical Work Developed per Second in each Resistance Worked.
(1) .	$\rho = \rho$	$a = n$	$\dfrac{K E^2 \rho}{M^2 N^2 \left(\dfrac{a R}{n} + \dfrac{r + \frac{\rho}{M}}{N n} + \dfrac{t}{n} \right)^2}$
(2) .	$\rho = \rho$	$a = a$	$\dfrac{K E^2 \rho}{M^2 N^2 \left(\dfrac{a R}{n} + \dfrac{r + \frac{\rho}{M}}{N a} + \dfrac{t}{a} \right)^2}$
(3) .	$\rho = \rho$	$a = \sqrt{\dfrac{n}{R}\left(\dfrac{r + \frac{\rho}{M}}{N} + t\right)}$	$\dfrac{K E^2 \rho}{\dfrac{4 M^2 N^2 R}{n}\left(\dfrac{r + \frac{\rho}{M}}{N} + t\right)}$
(4) .	$\rho = MN\left(\dfrac{a^2}{n} R + \dfrac{r}{N} + t\right)$	$a = a$	$\dfrac{K E^2}{4 M N \left(\dfrac{R}{n} + \dfrac{r}{N a^2} + \dfrac{t}{a^2}\right)}$
(5) .	$\rho = MN\left(n R + \dfrac{r}{N} + t\right)$	$a = n$	$\dfrac{K E^2}{4 M N \left(\dfrac{R}{n} + \dfrac{r}{n^2} + \dfrac{t}{n^2}\right)}$

By making $t = o$, the case occurs for completion of circuit without earth. It may be remarked that these formulæ comprehend all the combinations in which m equal resistances in series constitute each of the resistances ρ. The value for these m resistances is the mth part of that for ρ, and the work recovered on each of these m resistances, partially worked, is the mth part of the total work recovered on each of the resistances worked as in the Tables.

The formulæ also show that it is possible to recover on a total circuit, worked under the conditions of maximum, work equal to a quarter of the energy of the resultant generator, terming by energy of the generator the work developed on the internal resistance resulting from the generator working on short circuit. If the total resistances worked are divided into several equal partial resistances, the total work recovered is divisible into an equal number of parts, whatever may be the mode of division employed, whether in tension or in derivation. To produce corresponding conditions of efficiency, and especially conditions of maximum efficiency, if a known worked resistance is substituted by m equal partial resistances, each of these partial resistances should be the mth part of the total resistance, if the division is in tension, and each m times the total resistance if in shunt or derived circuits.

It is interesting to ascertain the degree of importance that should be attached to the realisation of the conditions of maximum. A being the ratio between the value of the total resistance really worked, and the total value that gives maximum conditions of efficiency, the ratio of the efficiency realised to the maximum efficiency realisable is given by $\frac{4}{A + \frac{1}{A} + 2}$, or $\left(\frac{2}{\sqrt{A} + \frac{1}{\sqrt{A}}}\right)^2$.

This expression does not vary when A is substituted by $\frac{1}{A}$, and shows that the loss of efficiency is proportional to the square of the amount of departure of the total resistance from that conducing to maximum efficiency.

P. H.

Comparative Merits of the Voltaic Batteries of Callaud, Marié-Davy, and Leclanché. By E. Caël.

(Annales Télégraphiques, 1879, p. 10.)

In this essay the Author gives the results of a series of experiments made at Lille upon the strength of current, cost of construction and maintenance, with other particulars of the voltaic batteries of the systems of M. Callaud, M. Marié-Davy, and M. Leclanché. The experiments were made on the following lines of telegraph, and extended over a period of more than three years: Lille and Dunkirk (53 miles), Lille and Brussels (75 miles), and Lille and

Havre (186 miles). In these experiments the strength of each current was measured several times a month, by the amount of deflection of a sine galvanometer placed in the circuit, and the results were recorded by a curve, of which the abscissæ represented the number of days from the beginning of the inquiry, and the ordinates the angular deflection of the galvanometer. The diagram demonstrates that both the Leclanché and the Marié-Davy batteries fell off in power soon after being started, but not at a uniform rate, as shown by the undulating or zig-zag nature of the descending curve. This variation in the strength of the current is due to a complication of causes, the principal of which are the variable polarisation of the electrodes, impurities in the plates and chemicals employed in the batteries, and the irregular amount of work which has been put upon them. The Callaud battery, on the contrary, does not attain its maximum power until it has been at work at least two months, and after a certain time, the glass vessels become encrusted with crystals of zinc sulphate, and the zinc elements become destroyed. By the renewal of the zincs, and by removing this incrustation periodically, the battery is restored to its proper strength. In these experiments the batteries were all started together on the 27th of June, 1875. The Callaud battery worked up to the 15th of June, 1877, without further attendance than the supply of the salt. By this time the zinc elements were almost entirely destroyed, and had to be renewed, and the incrustation of zinc sulphate was removed. These operations immediately restored the battery to its full strength, which did not fall off again until the end of the experiments, that is to say, until the 22nd of July, 1878. The Marié-Davy battery attained immediately on being started its maximum strength, which steadily decreased during the first two months, recovering itself a little at the end of that time, and, after varying considerably, it became, by the end of October 1877, too enfeebled to work the long line to Havre, and it was placed on the Brussels line for another year, at the end of which time it had become fairly worked out. The Leclanché battery was much more powerful than the other two at the commencement of the experiments, but its power soon began to decrease by the polarisation of its plates, and after working for eighteen months its power was no greater than its two competitors. After the 15th of September, 1877, it became impossible to employ the Leclanché on the Brussels line, but it was able to work the Dunkirk line until the 22nd of July, 1878, when it had to be cast aside, thus bringing the experiments to a close. The following table shows the number of messages transmitted by the three batteries respectively during the three years, the cost of the maintenance during the same period, and the cost per message transmitted:

	Number of Messages.	Cost.	Cost per Message.
		Francs.	Francs.
Callaud	98,135	65·16	0·00068
Marié-Davy	90,067	59·40	0·00066
Leclanché	98,594	47·20	0·00048

From the above results M. Caël has arrived at the conclusion that for telegraph purposes the small size Callaud battery is inapplicable, but he recommends, where this system is adopted, the employment of the large size; he however prefers the Leclanché battery to both the Callaud and the Marié-Davy, on account of the ease with which it can be charged and maintained in working order, the harmlessness and low cost of the salts employed, and the satisfactory results obtained by working it simultaneously on several currents of equal resistance.

C. W. C.

Apparatus for Testing Metallic Telegraph Poles.

(Annales Télégraphiques, 1879, p. 1.)

In the year 1875 a Commission was appointed in Paris by the Telegraph Administration, for investigating the question of employing iron in the construction of telegraph poles, and for testing the rigidity of iron poles of various sections. The Commission designed the apparatus described in this article, which was constructed by M. Thomasset, of Paris. The pole to be tested is fixed in a vertical position, by its lower end being held between suitable clamping pieces, which are placed in a small circular pit about 3 feet deep, and are constructed to allow the pole to be rotated on its axis, so as to be tested for flexure in various directions perpendicular to its axis. At a distance of about 10 feet from the mouth of this pit is erected the machine, by which the strains are not only given to the pole, but are measured at the same time. This machine consists of a pair of vertical guides of I iron, about 40 feet high, attached to a framing of T iron, and so trussed as to withstand a horizontal pull of 2 tons without deflection. Upon these guides slides a block to which a pulley is attached, and which can be raised or lowered to any convenient height by means of a chain passing over a fixed pulley at the top of the guides to a small winding drum attached to the framing. In testing a telegraph pole fixed in the pit, a wire cord is firmly made fast to its upper extremity, and passing over the sliding pulley (which is placed at the same height so as to insure a horizontal pull on the pole) is attached to the end of a screw fixed vertically below the sliding pulley. This screw can be drawn down by a nut, which is rotated by hand gearing, the effect of which is to draw the cord downwards, giving a horizontal pull to the top of the pole under examination, whose deflection is measured on a scale at the same time as the tensional strain is indicated by means of a dynamometer, the readings of which are given by a mercurial manometer. To render a description of this interesting apparatus clear, drawings would be required. The original article

is accompanied by illustrations of the whole apparatus, as well as of the manometric dynamometer.

C. W. C.

Portable Automatic Morse Manipulator. By Capt. COLOMB.

(Revue d'Artillerie, vol. xiv., p. 265.)

The Author has endeavoured to simplify the manipulation of the apparatus used in military telegraphy. The Morse key, although apparently a most simple instrument, is too delicate in its use for military employment, necessitating long training of both hand and ear. The sending apparatus designed by the Author consists of two parts, the signal plate and the expeditor, connected by flexible conducting wires. The signal plate has on it the letters of the alphabet and the numerals. From opposite to each letter or numeral proceeds a groove having its floor composed of alternate conducting and non-conducting pieces of the suitable dot and dash lengths. The conducting pieces are in contact with a bottom metallic plate which is connected to one pole of the battery, the other pole being put to earth. The expeditor is a wooden handle, containing a straight steel spring carrying a wheel, which is put in connection through a contact, also contained in the handle, communicating with line. As the wheel is drawn by hand over the conducting and non-conducting signs in the signal plate, the requisite contacts and breaks are made in the expeditor, and these contacts determine the length and order of the electrical impulses constituting the letters.

P. H.

Cables without Induction. By F. GERALDY.

(La Lumière Electrique, vol. i., p. 58.)

There has been for some time in use in America a cable system with multiple wires, in which inductive effects are said to be avoided. The cable consists of a metallic tube, into which are introduced the conducting wires, and these may be very fine and in considerable number. The wires are covered simply with cotton. Paraffin oil is filled into the tube, so as to immerse the conductors in a liquid insulator, and this is said to remove the effects of induction by reason of the mobility of the liquid molecules impeding electrotonic conductivity. The system is due to Mr. Brooks.

P. H.

Magneto-Electric Machines. By A. Breguet.

(Annales de Chimie et de Physique, vol. xvi.. p. 5.)

The Gramme machine is reversible: the rotation of its bobbin gives rise to an electric current; and reciprocally, if a current traverses the bobbin, the latter is caused to revolve. Because of this complete reversibility, all theories should be equally acceptable for both functions of the machine. The usual demonstrations do not fulfil this condition; but the Author shows that if the Gramme ring be considered as an extension of Barlow's wheel, theoretical views can be taken, of the greatest simplicity. As is well known, Barlow's wheel consists of a metallic conductor bent twice at right angles, and supported at the middle of its length on the point of a vertical axis, the axis of rotation of the system. The bent branches are parallel with this axis, and dip at their lower ends into a circular canal containing mercury; this canal is divided by ebonite partitions into equal parts, which are connected to the poles of a battery. The current from the battery passes to one semicircular canal of mercury, up one bent arm of the conductor, along the horizontal member, and down the other bent arm to the other semicircular canal of mercury. The whole apparatus is placed between the poles of a powerful permanent magnet, so that the diameter formed by the ebonite partitions is perpendicular to the line joining the magnet poles. On completion of the circuit the conductor commences and continues to rotate. The Author, to simplify explanation, terms the diameter formed by the partitions the diameter of commutation; and the magnetic field developed by the currents of the moving parts, the galvanic field, to avoid confusion with the magnetic field properly so called. If several convolutions are substituted for the single wire, the moment of revolving force will be increased proportionately to the number of the convolutions, provided that the resistance introduced by the increased length of wire does not sensibly reduce the strength of the current.

If a continuous frame be formed, so that in four crossings the wire on the upper part of the frame, as it is brought up, is at right angles to the crossing by which the wire was carried down, an approximation to the Alteneck (Siemens) armature is obtained, the commutation in this case being arranged by four pieces pendant from the lower part of the frame.

If an iron cylindrical ring be arranged so that the axis of this ring is parallel to the axis of rotation of the wire conductor, which passes up the outside of one diameter of the cylinder, down upon the inside of the cylinder, across to the inside of the cylinder upon the further part of the diameter, returning to the mercurial commutator by the outside of the cylindrical ring, an approximation is obtained to the Gramme ring. The iron cylinder acts as a magnetic screen, cutting off the action of the permanent magnet upon the interior wires, as in the Gramme machine.

The Author points out theoretical views confirming the experiment made by Lippmann, to prove that magnetic screens acting as armatures cease to fulfil this function when under movement of translation. This arises from the ring or screen, which in a state of rest concentrates or deviates upon itself the lines of force, when in movement taking up and abandoning an equal number of these lines in a given time, rendering its concentrative effect nil.

If d be the diameter, and e the width or length of a Gramme or Alteneck bobbin, the length of wire necessary to a complete convolution is in the Gramme bobbin $4\,e$, and in the Alteneck bobbin $2\,(e + d)$, no account being taken of the extra length due to superposition of the layers of wire. If $4\,e < 2\,(e + d)$, the Gramme will be more effective, and if $4\,e > 2\,(e + d)$, less effective, than the Alteneck machine; if $4\,e = 2\,(e + d)$, the two machines will furnish identical currents. This equation being equivalent to $e = d$, according as the width or length of the bobbin is less or greater than its diameter, so will the Gramme machine be superior or inferior to that of Alteneck. The Author considers that a drawback to the efficiency of the Alteneck machine is the necessity of fastening down the wires on the cylinder by bands, to prevent the wires, during centrifugal action, bowing out into contact with the exciting magnets, because these bands prevent the active wires being brought in such close proximity to the exciting magnets as in the Gramme machine, where the shortness of the wire does not call for this binding down.

In conclusion, the Author seeks to prove that, whilst the soft iron armature of the Alteneck machine serves merely to reinforce the magnetic field in the region of the moving circuit, the annular core of the Gramme machine withdraws the internal wires of its armature from the normal action of the lines of force of the field; that the angular displacement of the commutators occurring with such machines is not due to retardation consequent upon time necessary to magnetise or demagnetise the soft iron cores, because such angular displacement occurs with machines not possessing iron cores; that, as has been shown in an earlier Paper, if the machine is to be used as an electromotor converting electricity into mechanical work, the angular displacement of the commutator brushes should be in a direction opposite to that of the rotation of the armature, and in the same direction as that of the rotation when the machine is employed as a generator of electric currents.

In a second Paper,[1] the Author describes various methods of winding the coils of the armatures of dynamo-electric machines:

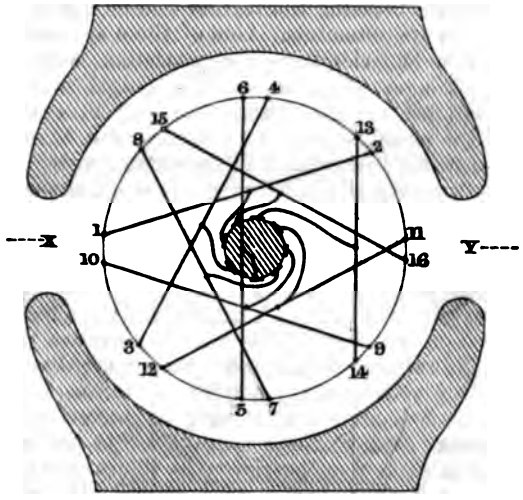
Alteneck's system.[2]—The wire is wound longitudinally on a cylinder, of which Fig. 1 represents one of the ends. All the convolutions traverse the opposite end by one of the diameters. Starting from 1, the wire crosses the nearer end by 1, 2, and

[1] Annales de Chimie et de Physique, vol. xvi., p. 282.

[2] The systems of winding of Alteneck and Frolich are those generally employed in the machine known as Siemens'.—P. H.

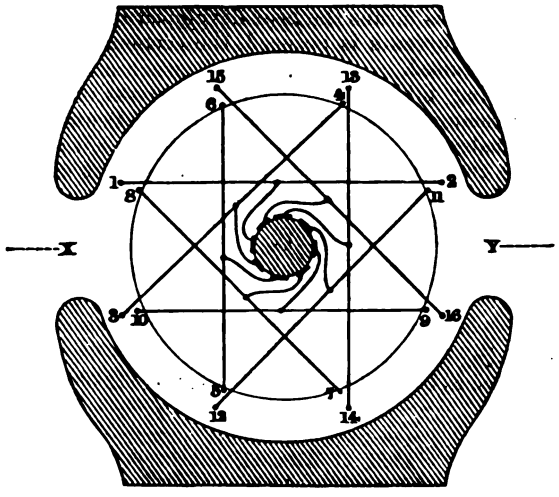
returns by 3 from the farther end of the cylinder, and so on. Fig. 1 also shows how each transversal branch is connected to the

FIG. 1.



eight metallic sectors, which during revolution of the cylinder are brought into contact with the wire brushes for collecting the current. The diameter X Y is that on which these points of contact occur. The poles of the magnet are above and beneath this diameter.

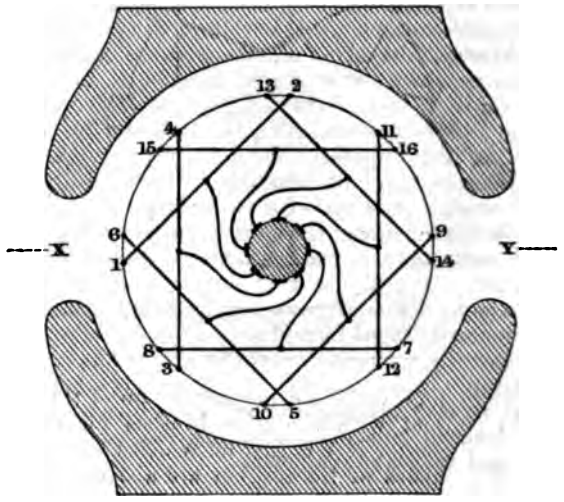
FIG. 2.



Frolich's system.[1]—The farther end is crossed by the wires following to its diameters.[2] The remaining connections will be understood from Fig. 2.

Breguet's system.—The Author proposes two systems of winding, in which the wires crossing the farther end of the cylinder do not necesarily follow its diameters. One of these systems is shown in Fig. 3, for which superiority to the preceding is claimed on the

FIG. 3.



ground that less strength of wire is required to produce the same results, and by this means the heat developed in the bobbin by the passage of the currents is reduced, the economic coefficient being proportionally raised.

The following table gives the four systems of winding in the order of increasing merit (the last being the best), and the numerical column indicates the length of inactive wire as a function of the radius of the ends of the cylinder. The length of effective wire is supposed to be the same in each case:

Frolich's system (Fig. 2)	30·8
Alteneck's „ (Fig. 1)	30·5
Breguet's „ (Fig. 4)	26·0

P. H.

[1] See note, p. 422.

[2] In each section of the cylinder are two layers of wires.—P.H.

Deprez' Electro-Motor. By Count DU MONCEL.

(La Lumière Electrique, vol. i., p. 50.)

Antecedent electro-motors require for their use currents of considerable energy. M. Marcel Deprez has produced a small electro-motor, giving useful work. The apparatus is 20 centimètres (= 7·87 inches) in length, and 15 centimètres (= 5·9 inches) in width, and produces 1·1 kilogrammètres (= 7·9 foot-lbs.) per second, when worked with five Bunsen elements. It consists of an 8-plate horseshoe magnet, 14½ centimètres (= 5·7 inches) in length, and between the arms of this magnet is introduced a Siemens armature, which receives the influence of the magnet for 7 centimètres (= 2·7 inches) in length. It has been usual to utilise only the polar extremities of the magnets in machines of this kind; but in this apparatus as much of the magnet is placed under contribution as may not come within the neutral zone. To effect this the armature is set with its axle parallel to the arms of the magnet instead of being (as is usual) at right angles thereto. On this axle is mounted the gear wheels necessary to obtain the required velocity. One of the revolving contact springs of the armature is made to act as a governor, by being caused to break circuit when the centrifugal force due to an extra velocity becomes too great to allow the spring to remain in contact. It is suggested that this electro-motor is quite sufficient to work a sewing machine, as it is difficult to stop the machine by hand, when actuated by the power of five Bunsen cells, even when the hand is applied to the pulley, which is 4 inches in diameter.

P. H.

Electric Lamps.

(Zeitschrift für angewandte Electricitätslehre, vol. i., pp. 168–177.)

There are, under this heading, two articles descriptive of electric lamps of Von Krupp's design and of Siemens and Halske's design. That of Krupp is similar in appearance to the Serrin lamp, which it is intended to supersede, as being of simpler construction. The carbon holders are regulated in their approximation by multiplying gear, controlled by a fly wheel, which works in mercury or oil. The carbons are separated by the action of an electro-magnet, imparted by an arm and lever to a kind of brake block, the brake pulling round the gear wheel, upon which it bears, when the carbons are required to be separated, in contrary direction to that in which the carbon holders cause the wheel to revolve by their gravitation. The brake thus either acts merely to check the revolution of the wheel, and consequently the approach of the carbons, or, when the current becomes too powerful, pulls the wheel round so as to separate the carbons.

The lamps designed by Siemens and Halske are ten in number, but are inclusive of modifications of three methods of action. In three lamps the design is similar to that adopted in Wilde's candle lamp. Two carbons are placed side by side, slightly inclined to each other, one or both of the carbons being drawn apart by the action of an electro-magnet upon an armature attached to a bent lever, of which the carbon forms the other continuation. Or, in another form, the carbons are inclined towards each other, and kept so by their own weight, the holders being hinged; and they are separated by a rod forced up between them by the action of the electro-magnet.

In four other forms of lamps the carbons are in the same vertical line. Under one form the lower carbon is borne upwards by a float in a cylinder of mercury, the upper carbon being withdrawn by an electro-magnet acting vertically. In another the lower carbon is fixed, the upper carbon being retarded in its descent by a spring pressing on the carbon, which is carried in a parallel motion, and drawn aside, when the current becomes too strong, by an electro-magnet acting upon an armature attached to the parallel motion. The remaining forms are modifications of those described.

P. H.

Thermo-Electric Lighting Batteries. By Count DU MONCEL.

(La Lumière Electrique, vol. i., p. 21.)

Seebeck's thermo-electric battery, invented in 1821, has long been considered as a generator of great constancy, but useless for practical purposes on account of the feeble strength of current obtainable. The introduction by Marcus of metallic alloys of considerable thermo-electric power, and the possibility of heating these without deterioration of the battery, presented a new phase in the construction of these instruments, successfully carried out by Farmer, Bunsen, Ed. Becquerel, Clamond, and Noé. In 1871 Clamond was constructing a battery of 1,500 large elements, from which he expected to obtain the electro-motive force of fifty Bunsen cells, and the Author then pointed out that if such a battery could be heated at no greater cost than that of the existing coke-heated batteries it would not involve a greater expense than 3*d.* per hour, and would become an economical source of electric light. But for the reason that the galena then employed changed by heat, this result was never attained. As the result of further experiment, Clamond has now constructed a thermo-electric battery, 1·5 mètres in height, 80 centimètres wide, which will furnish four electric lights, each of 150 to 200 candle-power, with an expenditure of 9½ kilogrammes (= 20·9 lbs.) of coke an hour. This result is of the greatest importance. Originally the Clamond battery consisted of bars of galena, soldered to plates of sheet iron; but the galena was given up for an alloy of antimony and zinc,

still preserving the sheet iron as the electro-positive plate. Elements of this combination were arranged in discs around a central flue; but in this system the electro-motive force of the couple was proportional to the difference of temperature of the two extremities of each bar, and it was therefore necessary that these bars should be long, to obtain energetic effect. The new instrument includes three distinct parts: (1). The collector, consisting of pieces of cast iron, so formed as to present a series of channels, in which heated air can circulate as provided from any suitable furnace. These pieces offer a large surface to the heated gases, and store up the heat that they subsequently communicate to the couples. (2). The heat diffuser, which forms the exterior of the apparatus, and consists of metallic plates, presenting considerable surface to the surrounding atmosphere. (3.) The thermo-electric system placed between the collector and the diffuser, and arranged so that the series opposed those joints participating in the different temperatures to these two parts. The length of the thermo-electric bars is restricted to as small limits as possible. The constituents of the alloy employed are not given; but the complete battery has an electro-motive force of 218 volts, consuming 19·8 lbs. of coal an hour. P. H.

Transmission and Distribution of Motive Power to Great Distances by Electricity. By A. ACHARD.

(Annales des Mines, 1879, p. 54–107.)

The Author refers to the cost of working with battery power in electromotors, and points out that the method to be described bears no relation to this expensive one, because the current is derived from another source, dependent upon the consumption of coal, and not upon that of metallic zinc. The principles of magneto-electric machines are considered in their simple mathematical phase, and the machines of Gramme, Siemens, Bürgin, Lontin, Wilde, and Ladd are described and illustrated. Hagenbach's experiments are quoted as to the electrical efficiency of the Gramme machine, which ranges as high as 93·5 per cent. The Author proceeds to discuss the state of the current resulting from the interposition in the circuit of a second machine, driven by the current from the first, and constituting a circuit as arranged for the transmission of motive power. A complete analogy is stated to exist between a circuit so arranged and a battery circuit employed in electrolysis. To obtain maximum efficiency in a distributed series of machines worked from one motor machine, it would appear that the resistances of the derived circuits, each carrying a machine, should be equal. But the Author considers that, before a complete solution to this question can be given, it is necessary to determine for the several types of machines the

relation existing between the intensity of the current and the magnetism of the inductor magnets, or, what is the same thing, the indivisible product of this magnetism by the constant for the machine, and to express this law approximately by an empirical formula sufficiently simple for use in ordinary calculations. A solid conductor would be of less advantage than a conductor composed of numerous fine wires, arranged to radiate the heat produced by the current to the best effect. The Author quotes from the Paper read by Dr. Higgs and Mr. Brittle before the Institution of Civil Engineers in 1877–78, which appears to have come to his hand after the preceding discussion.

P. H.

The Origin of Sounds in the Telephone. By Count DU MONCEL.

(Comptes rendus de l'Académie des Sciences, vol. lxxxviii., p. 1119.)

Experiments by Spottiswoode, Warwick, Canestrelli, Paul Boy, Millar, Lloyd, and others, and especially by Ader, have demonstrated that speech can be reproduced by a magnetic core simply wound with an electro-magnetic helix; but in the majority of these experiments a speaking microphone has been employed, actuated by a battery having more or less energy. It might therefore be objected, that if a battery be necessary to set up the vibrations, the vibrations could not be obtained with the feeble currents generated in the Bell telephone; and that thus the explanation formerly given by the Author of the origin of the effects produced in the Bell telephone was not completely justified by these experiments. The Author has now made an experiment, which he believes conclusively proves the correctness of his views as formerly expressed. This experiment consisted in speaking through a telephone, and using as the receiver a fragment of watchspring fixed on a small plate of wood, and enveloped, where in contact with the plate, by a small helix of fine (No. 32) wire. This fragment of spring, which is about 2 centimètres longer than the bobbin, is strongly magnetised; and when the wire helix is connected in the telephonic circuit, it is sufficient to apply the plate of wood to the ear to receive very distinctly the words pronounced in the telephone. The Author says it is therefore certain that sounds reproduced in the Bell telephone are the result of molecular movements in the diaphragm due to its magnetisation and demagnetisation; and that the extra effects of the diaphragm are due to its action as an armature to the magnetised core. Laborde, however, has shown that a diaphragm of iron forming an attachment to the elongation of the magnet core, or even a diaphragm of non-magnetic material, serves to transmit sounds, of energy commensurate with the energy communicated to the magnetic system. In favour of the theory of molecular disturbance, it is difficult to imagine that currents, which are, according to Galileo Ferraris, of strength equal to that

ierated by a Daniell element in a circuit of ordinary telegraph e of a length sufficient to surround our earth seventy times, can duce electro-magnetic attractions capable of creating the ltiple vibrations that constitute the sounds of speech.

P. H.

Electricity as a Ferment. By M. Berthelot.

(Annales de Chemie et de Physique, vol. xvi. p. 450.)

The Author describes an experiment, which, if it does not resolve problem of the transformation of sugar into alcohol by inanic agents, throws considerable light upon the subject. He endeavoured to realise the simultaneous conditions of hydroisation and of oxidation of sugar by the following artificial ans. A battery of six to eight Bunsen elements was arranged connection with an oscillating commutator, so as to give ernately positive and negative currents 12 to 15 times a ond, to two cylinders of spongy platinum acting as electrodes. ese platinum cylinders were immersed in acidulated water, l the contacts were so arranged that neither hydrogen nor ygen was disengaged, the water being re-formed as soon as omposed. Thus regulated, the electrodes of the apparatus were mersed in an aqueous solution of glucose. Alcohol in very small antities was obtained. The result is insufficient to authorise a inite conclusion; but the fact of the production of alcohol, in cold, from sugar submitted to electrolysis, is worthy of notice.[1]

P. H.

Oxidation of Alcohols by Electrolysis. By A. Renard.

(Annales de Chimie et de Physique, vol. xvi., p. 289.)

Electrolysis has been chiefly studied in its relations to mineral mistry. Excepting the electrolysis of organic acids and their aline salts, the application of electrolysis to organic chemistry been neglected, although these isolated experiments have given arkable results. The Author has investigated the subject of oxidation of the principal alcohols by the gas yielded during trolysis, and has obtained results of so favourable a nature as lead him to prefer this method of oxidation to the ordinary cesses, as it has the advantage of being effected at a low temature and in the presence of weak reagents, and allows,

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[1] The Author appears unaware of the obverse fact, due to a Swedish authority, beers turned slightly sour by atmospheric electric influence have been nerated by electric currents.—P. H.

therefore, of more easily learning the different phases by which the substances become oxidised before they are completely consumed and transformed into the ultimate products, carbonic acid and carbonic oxide. According to Berthelot's recent experiments, electrolysis, besides yielding oxygen and hydrogen, also produces persulphuric acid, ozone, and oxygenated water; under the conditions of the Author's experiments these products either did not occur or their effect was rendered null. The phenomena are therefore confined to the decomposition of the acidulated water with formation of hydrogen and oxygen, and the fixation of the oxygen upon the alcohol. The hydrogen disengaged was found to have no effect upon the alcohols experimented with, since when its electrode was enclosed in a porous vessel the alcohol contained therein was not subject to any alteration. The Author considers that this method of oxidation might be advantageously applied in the study of numerous other organic substances.

The battery employed was of Bunsen elements of about 1·5 litre capacity, in which the zinc cylinder was replaced by a cylinder of cast iron, carrying a lug, to which is riveted a copper strip, curved at right angles, and immersed at its free end in a mercury cup, formed in the carbon of the adjoining cell. This battery can be rapidly mounted, and is economical, owing to the absence of amalgamation and to the substitution of iron for zinc. Each iron cylinder weighs 4·4 lbs., and will suffice in constant use for a period of two months; the quantity of electricity furnished being about three-fourths of that given by a battery constructed with zinc cylinders.

P. H.

Unipolar Induction, Atmospheric Electricity, and the Aurora Borealis. By E. EDLUND.

(Annales de Chemie et de Physique, vol. xvi., pp. 49–107; and Kongl. Svenska Vetenkaps-Akademiens Handlingar, vol. xvi. p. 1.)

Let a steel magnet be arranged in a vertical position, readily set in rotation about its geometric axis, and surrounded by a metallic muff in the form of a cylinder, also capable of turning about the same axis. The current from a battery being caused to pass into this cylinder, so that one of the electrodes is in contact with the cylinder near the poles of the magnet, and the second electrode at a point between the two poles, the cylinder will begin to rotate about the magnet. The direction of rotation depends on that of the current in the cylinder, and on the situation of the poles. The magnet itself remains perfectly motionless, consequently the current does not exert upon it any rotary action. It is therefore possible to turn the magnet mechanically around its axis without the slightest resistance being offered by the reciprocal

ion of the magnet and current. The Author has previously wn,[1] that, according to the mechanical theory of heat, every phenomenon will be accompanied by phenomena of unipolar uction. If the battery is removed, and replaced by a galvano-ter, the latter will indicate a current as soon as the cylinder is hanically put in motion. This kind of induction has been ned unipolar induction. The current produced is proportional the velocity of the cylinder. The simultaneous mechanical ation of the magnet produces no increase in the current generated rotation of the cylinder. Plücker has proved experimentally t in this case the rotation of the magnet is incapable of pro-ing a current. For the magnet a solenoid can be substituted, ducing the same effect.[2] Edlund has shown that the rotation a solenoid about its axis cannot produce a unipolar induction rent. It is, therefore, the rotation of the cylinder about the gnet that gives rise to the unipolar induced current; while the ation of the magnet about its axis has nothing to do with the nomenon. If the magnet and cylinder are connected together, as to form a compact body, the magnet is carried in the direc-n of the rotation of the cylinder, without any modification in induction of the magnet. The magnet acts in this case on the inder as if the former were immovable and the latter rotating. at the magnet cannot produce unipolar induction, in a con-tor with which it is intimately united, is therefore not correct. the radius of the cylinder be sufficiently reduced for the cylinder be in perfect contact with the magnet, this circumstance will prevent induction occurring in the cylinder; and because this uction will be produced irrespective of the thickness of the inder, the latter can be entirely removed, and the terminals of galvanometer put into immediate contact with the magnet, hout causing the induction to cease. The magnet, then, per-ms the functions of a conductor, and the induction does not ult from its being put in rotation as a magnet, but as a con-tor. This unipolar induction was first studied by W. Weber.[3] e induction at any point of the conductor depends upon its tion relatively to the magnet regarded as a fixed point. As is own, this relative motion undergoes no modification if to the gnet as well as to the point in question equal velocities in the ne direction be imparted.

Unipolar induction ought not to be considered a real induction, t an ordinary electro-dynamic phenomenon, due to the action of magnet upon the electric currents produced by the rotative tion of the conductor. As for the action of the magnet, whether currents on which it acts are produced by particular electro-tive forces, or by the electric fluid being conveyed in the ection of motion of the conductor, is immaterial. If unipolar nomena are regarded as belonging to those of induction, it is

[1] Wiedemann's Annalen, vol. ii., p. 347. [2] Pogg. Ann. vol. clx., p. 604.
[3] *Ibid.*, vol. liii., p. 353.

necessary to distinguish the following kinds of magnetic induction: (1). Induction due to the action of the magnet upon the induced circuit augmenting or diminishing, or undergoing variation. This may occur either by the magnetic moment undergoing a change, while the induced circuit and the magnet remain at rest, and consequently do not alter their relative position; or the magnet and the induced circuit approach towards or recede from each other without the magnetic moment undergoing variation. (2). Induction due to the circumstance that the conductor moves, in regard to the magnet, without the distance from the poles of the latter to the different points of the conductor necessarily varying, and without increase or diminution of the magnetic moment; and this is unipolar induction. These different kinds of induction may be present in combination.

In a second part of the Paper the Author treats of atmospheric electricity and the aurora borealis. The earth may be considered as a relatively good conductor of electricity, and the atmosphere as a bad conductor. Its conductivity, which depends almost exclusively upon the amount of humidity, is subject to incessant variation. As the density of the air diminishes, its conductivity increases, and there should consequently exist, at a considerable height, a stratum of air of moderate conductivity. The surface of the earth is immediately surrounded by a stratum of air of low conductivity, subject to incessant variation, and to this layer succeeds another, of which the conductivity is greater, and sensibly invariable. The magnetic action of the earth cannot be entirely explained as due to a magnetic mass, making a certain angle with the plane of rotation, for the magnetic action is too irregular; but the idea is sufficiently correct. The magnetism of the earth may be considered as acting upon an element of current situated in the atmosphere, with a force capable of being resolved into components, that in the direction of the dipping-needle being zero. In equatorial regions, or in low latitudes, the force of terrestrial magnetic induction is very intense, and renders the atmosphere electro-positive; the resistance to discharge is also great. When the vapour of water in the air condenses to form clouds, these become charged with electric fluid. The cloud, which is a good conductor, is thus charged with positive electricity. Clouds, negatively charged by induction from the positively-charged clouds, are also formed. If the charges are sufficiently intense, the clouds may become discharged to earth instantaneously in low latitudes; but in higher latitudes, where the resistance of the air is less, these discharges are transformed into slow and continuous currents, giving rise to the phenomenon known as the aurora borealis. The annual period of frequency of this phenomenon is due to the electricity accumulated in the atmosphere by the unipolar induction of the terrestrial magnet, and this descending to the earth either as a storm of great intensity or as a slow and continuous discharge, gives the phenomena of storms at the equator and of the aurora at the poles. The consequences of this theory

are examined at length, and the Author shows that unipolar induction plays too important and significant a part in these phenomena to be neglected in their consideration.

P. H.

Gas from Petroleum Oils at Low Temperatures.

(Annales du Génie civil, May 1879, p. 378).

Messrs. Wirth and Co., Frankfort, have constructed simple apparatus for the manufacture of gas from the light products yielded in the refining of petroleum, known as gazoline, essence of petroleum, &c. These products are volatilised at ordinary temperatures, and the more readily as they are lighter. When air is introduced into the vapour, a mechanical mixture is formed, and a gas is yielded which burns with a brilliancy proportional to the quantity of carburetted matter it contains. The function of the apparatus is to vaporise the gazoline by means of air, which may either be passed over or through the material. The temperature of the liquid is lowered as the vaporisation proceeds, whilst its specific gravity is increased; and, in order to ensure a uniform result, it is necessary that the cold produced should be compensated by a supply of artificial heat, and that the substance should be homogeneous.

According to one arrangement, the gazoline is supplied drop by drop to the carburator in which it is vaporised, and mixed with air. The air is supplied from a reservoir under pressure, the power for supplying which is derived from a falling weight. The heat absorbed by vaporisation is restored by means of a water heating-apparatus, heated by a gas jet. An apparatus of twenty-five burners requires one square mètre, or $10\frac{3}{4}$ square feet, of vaporising surface, and costs £42. One pound of gazoline, costing $3\frac{1}{2}d.$, yields 1 cubic yard of gas. The gas possesses an illuminating power as 5 to 3 for that of coal gas. The heating powers are the same.

D. K. C.

Pyrometers. By F. Fischer.

(Dingler's Polytechnisches Journal, 1878, p. 319.)

The Author describes several modifications of instruments for measuring intense heat.

In Tremeschini and Lion's pyrometer, a fire-clay tube is introduced into the heat, and the hot air conducted from it into a copper tube, contiguous to which a sensitive metallic thermometer is placed, this latter being so arranged that its distance from the copper tube is adjustable. If the thermometer is placed at such a distance that it always shows a particular degree of heat, then the

temperature to be measured corresponds to the square roots of the distance between it and the copper tube.

MacDonald's pyrometer is a metal or porcelain tube, filled with anhydrous nitrogen, and combined with a Bourdon gauge, provided with suitably graduated dials to indicate the temperature.

Maier's pyrometer consists of an iron tube inclosing a central rod or axle, round which a spiral metallic ribbon is wound, one end of the axle being fitted to the tube. During the process of heating the ribbon is unwound, and causes the rotation of the central rod, which communicates the rotary movement, by suitable mechanism, to the pointer moving over the dial.

Zaabel's pyrometer is based upon the principle of observations made on differential expansion of rods or tubes of copper and iron. Enclosed in an outer protecting tube is another tube of brass, or, for temperatures up to 900° centigrade (1,652° Fahr.), of copper; this is attached to the upper part and across the indicating mechanism. Within the copper tube is a second of the same metal, surrounding a steel tube, and this is also connected to the indicator. If the instrument is put into the heat the copper tubes are heated and expanded equally, the steel tube a little more, which difference is shown by the indicating mechanism.

In Steinle and Hartung's pyrometer three tubes are arranged, one within the other, the two inner tubes being perforated throughout their entire length, and supporting the usual dial and indicator. The inner tubes also project beyond their covering. The centre rod is formed, for some part of its length, of a solid stick of graphite. As soon as this is applied to heat its length is altered, and an indication of the same transmitted to the dial. It is claimed, that the length of the outer protecting tube may be altered at will, without affecting the indication; whilst the inner tubes, being perforated, and consequently enveloped in a jacket of air, always keep the same temperature and preserve the same length. Means are provided for regulating the position of the pointer. E. S.

On a New Pyrometer. By Dr. E. Buchner.

(Dingler's Polytechnisches Journal, vol. ccxxxii., p. 429.)

During an investigation into the action of ultramarine muffle furnaces, the Author had occasion to determine temperatures up to 900° centigrade (1,652° Fahr.) For this purpose he tried a graphite pyrometer by Steinle and Hartung, and also a calorimeter, but the pyrometer proved quite unreliable for temperatures above 650° centigrade (1,202° Fahr.), and the calorimeter method, though exact, was both slow and troublesome. The most satisfactory method in practice was found to be the use of alloys and metals whose melting points had been previously determined, and the Author designed the apparatus described, in order automatically

to register the exact moment at which a given alloy melts in the interior of a furnace.

The apparatus consists of a vertical tube of refractory material, which dips deeply into the muffle; inside this a small crucible is hung from a scale beam above; in the bottom of the crucible is a hole, so that when the alloy melts it runs through into a dish suspended underneath. This causes the scale beam to rise, and the motion of the beam, by electrical contact, rings a bell, and marks a dot on a sheet of paper travelled by clockwork; this registers the exact time at which the melting-point is reached. The melted metal can be lifted out and preserved for future use.

This method registers only a series of definite temperatures, but proved quite sufficient in practical use.

W. P.

The Metric System of Weights and Measures in the United States.

(Proceedings of the Civil Engineers' Club of the North West, May 5, 1879.)

At a recent meeting of the Civil Engineers' Club of the North-West, at Chicago, a report was received from the committee appointed by the club to consider the question of the compulsory adoption of the metric system, the use of which has been permissive in the United States since 1866. While the committee fully recognise the desirability of adopting the system, they shrink from enforcing it by legislation, as such a course would involve the loss, total or partial, of all the present apparatus for weighing and measuring, and of a vast amount of machinery, patterns, drawings, models, tables, books and records, &c., which have been made upon the present standards. A still greater obstacle they believe to be the simple inertia of the great mass of the population, who have never heard of the metric system, and who know and care absolutely nothing about it. In order gradually to overcome this inertia the committee think a long process of familiarising the people with the new standards will be necessary. They recommend that the metric system should be taught in all the national schools, and that the Civil Engineers' Club join the Boston Society of Civil Engineers in their petition to Congress, as set forth in the report of the standing Committee on the Metric System, dated March 19, 1879. They further urge that a prayer should be added to that petition, that on and after the date fixed in such petition (July 1, 1881) all material bought, or work done, for the United States Government, in any of its departments, be measured or estimated by metric standards only, except such as relate to public buildings or other works whose construction has been begun with the present standards, and to contracts in force previously to that date.

In the discussion which followed the presentation of the report, Mr. Charles Latimer spoke at length in opposition to any adoption of the metric weights and measures, permissive or compulsory

The chief points urged by Mr. Latimer were: 1. The danger of arousing the opposition of the people, who had no vehement desire to overturn established institutions such as that which prevailed in France when the metric system was established and formed a powerful element in overcoming popular resistance. 2. The claim that it was an exact and scientific unit could no longer be put forth in face of the proved fact that the mètre did not coincide with the 10,000,000th part of a quadrant of the earth's meridian, more exact measurements having shown that quadrant to be equal to 10,000,850 mètres. 3. Was "The dictation of a few, the inhabitants of a small State about as large as Pennsylvania," to prevail over the great States of the world inhabited by the English-speaking people, who, with their dependencies, numbered 256,000,000 as against 164,000,000 who had adopted the metric system? 4. The superiority of units such as the inch, foot, and yard, which were natural measures of great antiquity, and could be, if desired, directly referred to the polar diameter of the earth—a straight line, over arbitrary units derived from curved lines, which differed in length at different parts of the earth's surface. 5. The judgment against it of some of the most learned men in France, England, and the United States. 6. The doubt whether the United States possessed the necessary power to enforce the system on the separate States. 7. The suspicion that the agitation was the action of a "ring" of interested individuals, who hoped to profit by having to make the new standards. Lastly, the great and immeasurable confusion which would result from the obligatory adoption of the system.

F. G. D.

Observations on Rolling and Pitching, made with the Double Oscillograph on board different Vessels. By L. E. Bertin.

(Mémoires présentés par divers savants à l'Académie des Sciences de l'Institût de France, vol. xxvi. No. 5.)

Two great advances have recently been made in understanding the laws of rolling, and the nautical qualities of ships, one of which is due to the application of exact theoretical principles in determining the pressure of the waves, and the other to the employment of effective practical methods in measuring the passive resistances.

For a small floating body exposed to the action of the waves, the position of equilibrium is always normal to the surface. In the case of a ship whose cross section is considerable as compared with the section of a wave, the angle θ_m made by the position of equilibrium with the vertical, is less than the angle θ which the surface of the water makes with the horizon. It is possible to deduce θ_m practically from θ by multiplying this latter by three known factors, μ, μ_1, μ_2, which are less than unity in proportion as the

vessel is larger or the waves shorter. μ and μ_1 express the effect of the variation in the direction of the elementary pressure at each point of the displaced volume; μ_2 takes account of the variation in magnitude of this pressure, in consequence of which the point of application of the resultant pressure changes its position. μ_2 depends on the dimensions and stability of a ship. $1-\mu_2$ is proportional, nearly, to the square of the ratio of the mean width of the hull l_m to the half length of the waves L, and also to the ratio of l_m to the metacentric height $\rho - a$.

The determination of the passive resistances has formed the subject of a previous Paper.[1] The immediate results of the study of rolling were to define the limits of the amplitude attainable. It is now possible to calculate the maximum angle of roll of any given vessel on a synchronous swell. The nautical qualities of ships are thus distinguished by the coefficient of the angle of inclination, $\rho = \sqrt{\frac{1}{N}}$; N being the coefficient of diminution of rolling; and ρ one of the factors of the amplitude of roll attainable under any circumstances.

The study of rolling is essentially experimental. Pure analysis will neither give the variation of amplitude between successive rolls, nor yet the influence on the amplitude, of the relation of the half periods T and Tn of the wave and the roll. It will not even give the exact equation of a single roll on a synchronous wave, nor the specific differences between such a roll and the swing of a pendulum, nor yet the marked difference between a roll as made with or against the wind.

As to pitching, it requires *ab initio* studies made at sea. Theory only gives the position of equilibrium on the waves and the moment of longitudinal stability. The moment of inertia may be calculated, but the moment of resistance to pitching can neither be measured nor evaluated from experiments in calm water.

The Author proceeds to describe the instrument used by him in measuring the rolling of ships, and the theory of its action. This instrument he calls a double oscillograph. It does not differ in principle from the instrument used by the late Mr. Froude in his experiments. Its principal parts are a large and a small pendulum, having periods of oscillation in the ratio of 320 to 1, and carrying tracers which inscribe curves on the opposite sides of a strip of paper, which travels between them at a perfectly uniform rate.

The large pendulum is formed of a slender disc, surrounded by a heavy ring. It weighs 193 kilogrammes, and its centre of gravity is 1·4 millemètres below its axis of suspension. Its period of oscillation is 80 seconds, which renders it insensible to the contrary actions of successive half waves and half rolls, the periods of which latter movements rarely exceed 20 seconds. This large pendulum consequently remains vertical, and should it by chance acquire a

[1] *Vide* Mémoires &c. sav. étrang. vol. xxii.

motion of its own, the disturbance due to this cause is easily recognised on the curves, and can consequently be corrected. This pendulum is used for giving the absolute inclination. The small pendulum whose period of oscillation is 0·4 second, is never influenced by its own inertia, and follows the variable direction of its position of equilibrium. It always tends to remain normal to the surface of the water, and consequently registers the roll of the ship relative to the effective wave surface.

The experiments made by the Author were conducted on board three vessels, the principal data of which bearing on the subject of rolling are given below:

	Navette.	Crocodile.	Annamite.
l. Length between perpendiculars . mètres	21·00	43·25	105·29
m. Breadth . . . . . „	3·80	7·30	15·32
p. Mean draught	1·595	2·51	6·45
P. Displacement . . . . . tonneaux	66·4	466	5,224
z. Distance from centre of hull to water-line . . . . . mètres	0·68	1·009	2·38
g. Distance from centre of gravity to water-line . . . . . mètre	−0·25	+0·192	+0·426
$\rho - a$. Metacentric height . . . . „	0·61	0·778	0·864
T n. Half period of roll in smooth water secs.	2·0	3·6	6·88
$\Sigma m r^2$. Moment of inertia $= \left(\frac{T n}{\pi}\right)^2 P (\rho - a)$.	16·42	476·9	21669
N. Coefficient of diminution of rolling . .	0·0129	0·033	0·0017
C. Coefficient of inclination $= \sqrt{\frac{1}{N}}$ . .	8·8	5·5	7·7
M_1. Moment of resistance $= 43\ N\ \Sigma\ m\ r^2$ tonneaux-m.	9·1	653	1,565

The "Crocodile" was provided with bilge keels, which gave her great resistance to rolling in the water; so much so that the coefficient of diminution of roll was double what it would otherwise have been. The total amplitude never extended beyond 7° on each side, whereas under ordinary circumstances it would certainly have reached from 10° to 15°.

The law that the half period of roll is smaller in proportion as the force of the wind is greater, is strikingly proved by the observations made on board the "Annamite." On leaving Cherbourg, the half period T n of roll in smooth water ought, according to the state of the cargo, to have been 6·80 seconds. Three and a half days afterwards, in fine weather, it was 7·01 seconds, the stability having diminished in consequence of the consumption of stores, but the effect of the wind caused T n to fall to 6·6 seconds, 6 seconds, and 5·75 seconds. These results are important enough to modify considerably the calculations affecting anchorage. The duration of a simple roll, if the amplitude attains 30°, is, in fact, reduced to four-sevenths of the half period in smooth water; and the tangential forces of inertia, being in vessels proportional to

the squares of the periods, are greater than allowed for in the old calculations, in the ratio of 49 to 16, or nearly 3 to 1.

The Author then gives an interesting series of plates of curves, recording his experiments on the rolling of all three vessels, and accompanies them with an analysis in the text of any peculiarities which they present.

In consequence of the great differences between the ships, the circumstances of the sea, and the relations between $T\,s$ and $T\,r$, these experiments furnish examples applicable to the majority of cases which arise in navigation.

The last section of the Paper is devoted to pitching, a subject which hitherto has received but little attention from investigators. It requires, even more than rolling, the use of an instrument which can measure at once the motion of the vessel and that of the water. The experiments were conducted on board the same vessels during the same voyages, and the results are given in a series of curves, as in the experiments on rolling. An examination of the curves shows at once a perfect isochronism between the waves and the absolute pitch. It also shows (what could not have been foreseen), that during all the experiments on board the "Annamite," the pitch was nothing else than the angular displacement of the position of equilibrium constantly taken up by the ship. In other words, the "Annamite" always remained perpendicular to the resultant of the weight and the force of inertia in the movement of translation, i.e., to the resultant pressure of the water, or to the direction of the small pendulum. This latter, indeed, traced a practically straight line. The undulations of the curve traced by the large pendulum represents, at the same time, the inclinations of the ship, and the movement of the mean wave which caused the pitch. The persistence with which this peculiarity appears on all the curves of the "Annamite" shows that it is not the expression of a peculiar phenomenon, but rather of a nearly general law.

The experiments on board the smallest vessel, the "Navette,' show clearly the existence of a relative, as well as of an absolute pitch, when the amplitude of the waves is considerable. The laws of pitching appear also to vary with the speed of the boat. There is a speed below which the relative pitch disappears completely, and above which it is very marked. These speeds, for any given vessel, vary as a function of the dimensions of the waves. The result of all the observations is as follows: The relative pitch having the character of a particular pendulatory movement, and having, like a roll, its own period, is never met with except in the particular case of a following sea having nearly the same speed as the vessel; it is even then very slight, and may be neglected in the presence of the pitch of waves of a variable period.

When the vessel is small, its speed considerable, and the sea rough, the relative pitch is produced with a period equal to that of the waves; each of its oscillations coincides with that of the

wave of which it is the result. The influence of the relative pitch on the total amplitude of the pitch depends on the mode of concordance between the relative pitch and the waves, which varies much. A certain speed is necessary for this concordance to produce an increase of the total pitch.

Between certain limits of the relation of the length and speed of the vessel and the dimensions of the waves, there is no relative pitch whatever. The vessel moves in following the angular motion of its position of equilibrium. A departure from the horizontal position may still be sensible at the two ends of the boat, but this is due simply to the curving of the surface of the water. When the pitch obeys such simple laws as these (which no doubt it does in the generality of cases), its amplitude may be determined beforehand, by calculations similar to those employed in the case of rolling, to fix the numerical value of the coefficient $\mu\,\mu_1\,\mu_2$.

In conclusion, the qualities of ships with regard to rolling and pitching differ very much on account of the ratio (which is much greater for pitching) of the moment of stability to that of inertia. In the case of the "Annamite" this ratio was ten times greater for pitching than for rolling; and no doubt the ratio of the moment of resistance to the moment of inertia is similarly greater. The distinctive feature of pitching, which should be taken advantage of as far as possible, lies in the vessel assuming the position of hydrostatic equilibrium without any relative motion, a position from which a vessel departs very considerably when rolling. To counteract the relative pitch, the relation between the moments of stability and resistance and the moment of longitudinal inertia must be increased as much as possible.

The principal rule to follow is to diminish the moment of inertia, and thus to return to the old rule of diminishing the weights at the ends, and loading the vessel amidships, in order to make it rise to the waves. It is well known that it is more advantageous to lighten the vessel forward rather than aft, because with a head sea the axis of rotation is situated well aft of the centre. The most efficacious method of diminishing the weight of the fore part, while preserving the maximum resistance and stability, consists in adopting a form of stem which gives the dead works a rapid entrance and forms a spur at the waterline. A considerable portion of the weight of the dead works is thus suppressed, and the anchors, cables, chase-guns, &c., are got further aft. In the case of the "Crocodile," if alterations of this nature were carried out, a 19-centimètre chase-gun, weighing 1·93 tonneau, could be used, instead of a 10-centimètre gun, weighing 1·86 tonneau. It has long been known from experience how greatly the presence or absence of such weights at the fore part of a vessel affects its pitching.

G. C. V. H.

Some Facts about the Great Tidal Wave, May 1877.[1]

By J. P. JOSEPHSON, Assoc. M. Inst. C.E.

(Transactions of the Royal Society, New South Wales, Dec. 4, 1878.)

This abnormal ocean wave was observed at Sydney, Newcastle, Ballina, Richmond river (in New South Wales), Brisbane (Queensland), Napier, Wellington, Christchurch, Akaroa, Omaru, Kaitangata, Lyttleton, &c. (New Zealand), Sandwich Islands, and South America.

The self-registering tide gauge at Sydney is fixed at Fort Denison, in a well 3 feet 6 inches diameter; and a tube 6 inches diameter connects it with the harbour. The registering apparatus is attached to a strong wooden table, with brass uprights supporting the brass cylinder, which is 5 inches in diameter and 24 inches long: to one end of the axis is attached a light wheel, 39 inches diameter, with a rim of thin sheet brass, the spokes being of brass tubing. A light brass chain, wound round once, is attached to a float—a copper ball 10 inches diameter—at one end, and at the other to a weight of 1 lb. Two horizontal rods are attached to the brass uprights, as guides for the pencil frame. In the clock on the axis of the hour hand is a wheel, 12 inches in circumference, with an attached cord passing out of the clock case to the pencil frame; it there passes over a pulley, and is attached to a weight sufficient to move the pencil frame. Any rise or fall in the float causes the cylinder to move, taking the paper under the pencil 2 inches for every foot of rise or fall. The clock by the hour hand unwinds the cord, and allows the pencil frame to move at the rate of 1 inch per hour. The effect of these two motions is to trace on the paper a curve corresponding to the tide. The extreme range of tide at Sydney is 6 feet 9 inches; the extreme difference between low-water springs and neaps is 2 feet 1 inch, the average being 1 foot, and the average difference between high and low water is 3 feet 4 inches. The harbour entrance between the North and South Heads is 1¼ mile wide; and the gauge being 3 miles up the harbour, the wave was doubtless partly broken. Between the 15th and 20th of August, 1868, a succession of waves reached Sydney, with an average interval of twenty-five minutes, and extreme oscillation of 34 inches, attributed to earthquake phenomena. The same occurred in August 1873, but not so marked in character. At Newcastle harbour, 60 miles north of Sydney, the wave appeared on the 11th of May, 1877; during the greatest oscillations the water fell 31 inches in ten minutes. The average interval between the waves was twenty-two minutes and the greatest oscillation 31 inches. At Ballina, 320 miles north of Sydney Heads, it was

[1] The description of the self-registering tide gauge is from a MS. communication supplied by the Author.

observed all day, the greatest rise being 18 inches. At Brisbane the tidal disturbances were observable, but this port did not possess a self-registering tide gauge. On the east coast of New Zealand similar disturbances were observable, the greatest range being 6 feet, and the least 2 feet—indicative of the movement being from the south-east, as no reports have been received from the west coast of New Zealand. On the coasts of the Sandwich Islands great disturbances were experienced. From Honolulu the difference between the highest and lowest tide mark was reported as 36 feet, and the rise as being 13 feet 6 inches above half-tide mark; a large loss of life and property was the consequence. There had been no local earthquakes, and it was inferred that the upheaval had occurred on the west coast of South America. The seaport of Iquique, Peru, distant from Sydney about 7,000 miles, suffered greatly from an earthquake on May 9th, the estimated damage amounting to £4,000,000. From Quito to Iquique, or one-third of the length of the South American Andes, the shock was felt with terrible distinctness. When earthquakes occur near the coast they are invariably followed by an upheaval of the water which assumes the shape of a tidal wave of greater or less magnitude, proving frequently more disastrous than the immediate results of the earthquake. The oscillations continued during the 11th, and it was not for several days that the tide resumed its customary ebb and flow. The line of the wave when crossing the Pacific is estimated to have measured 8,000 miles. The great wave of 1868 was estimated to have travelled at from 300 to 400 miles per hour. At Honolulu the sea oscillated three or four days, and many of the islands in the South Seas were totally submerged until the water had receded.[1]

J. B. R.

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[1] The three tidal diagrams accompanying the Paper illustrate clearly those remarkable abnormal pulsations repeated constantly during the whole period of the semi-diurnal tide. The first diagram, from 9 A.M., May 10th, to 9 A.M., May 11th, 1877, exhibits the curves as taken by the two registering machines at Sydney and Newcastle, presenting the usual tidal curves up to 6 A.M. on May 11th, when for three hours the registration is a violently jagged line.

The second diagram of the tidal curve, for May 11th and 12th, presents this violently agitated record throughout the entire twenty-four hours. Those for May 12th and 15th, 1877, present the same remarkable appearances during the entire record.

The genesis of these fluctuations is herein attributable to South American volcanic agency. But it may be remarked that Capt. Evans, R.N., Her Majesty's Hydrographer, has suggested in one of his Papers that these abnormal tidal pulsations may also be caused by the tilting over of the vast masses of ice from the Antarctic glaciers.—J. B. R.

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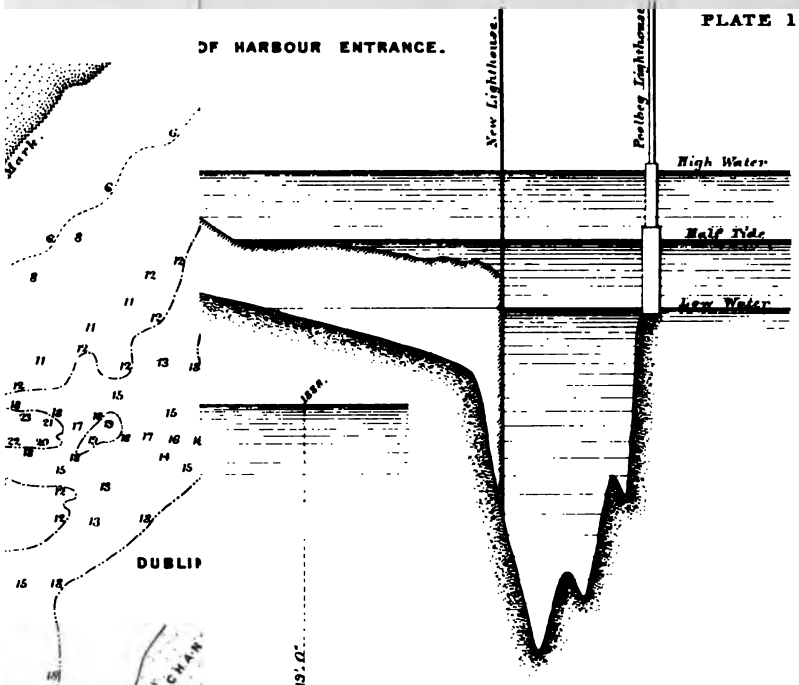
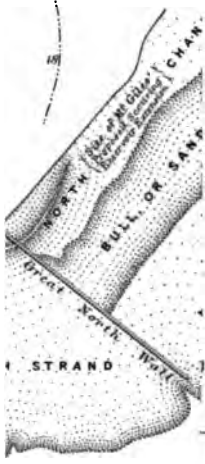
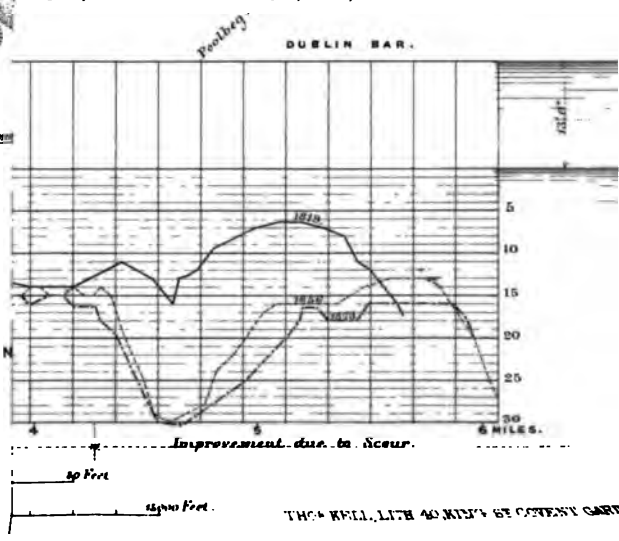




STRAND IN BAR, FOR THE YEARS 1818, 1856, 1878.



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THOS. KELL, LITH 40 KING'S ST COVENT GARDEN

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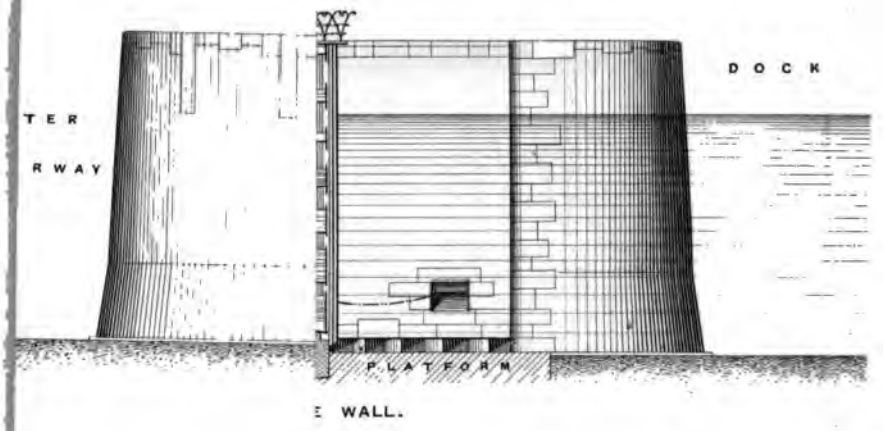

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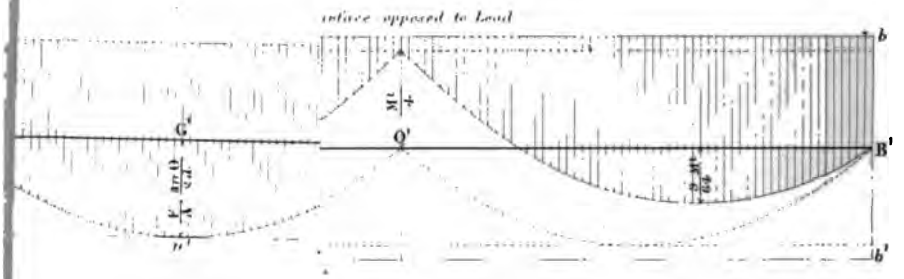

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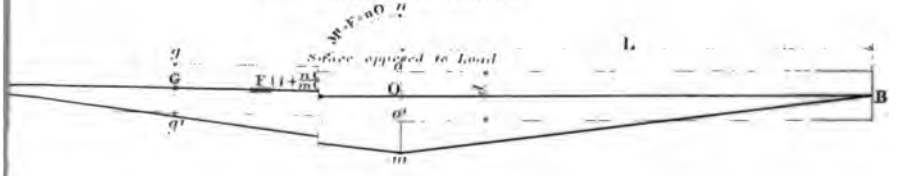

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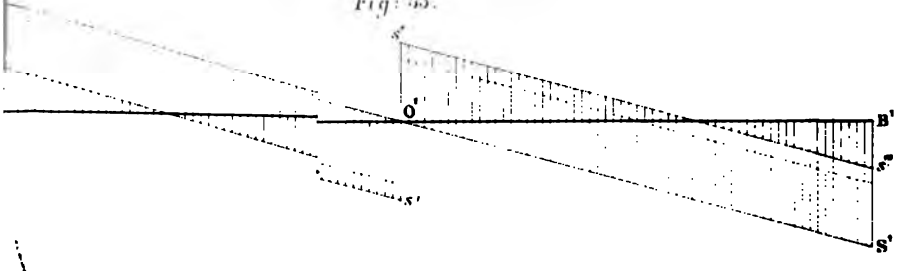

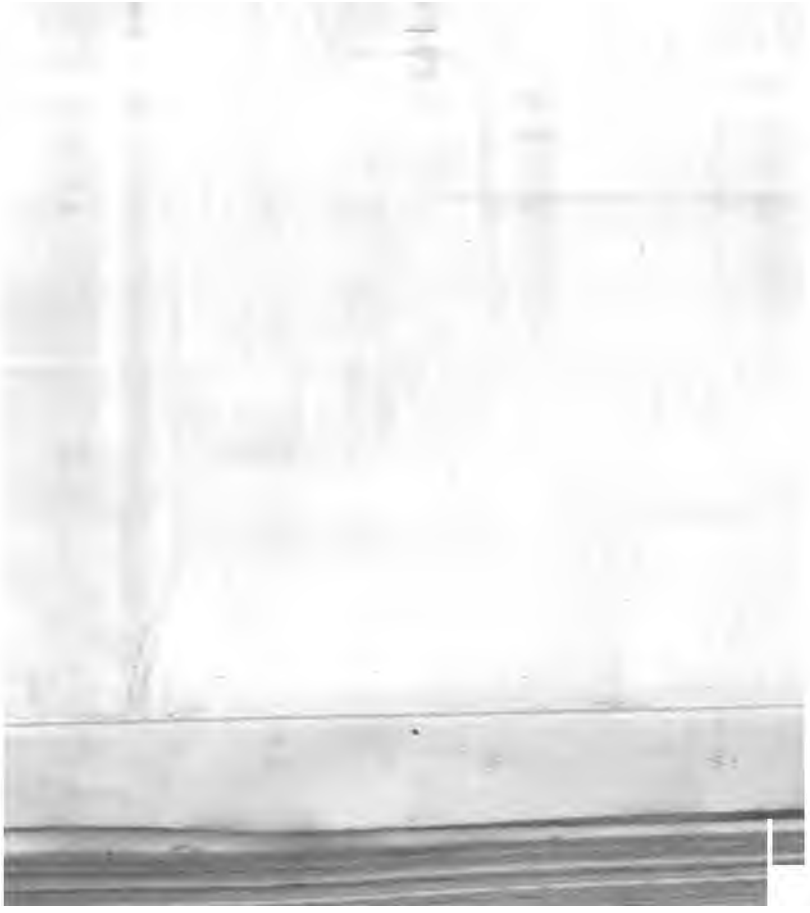

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Floor Line.

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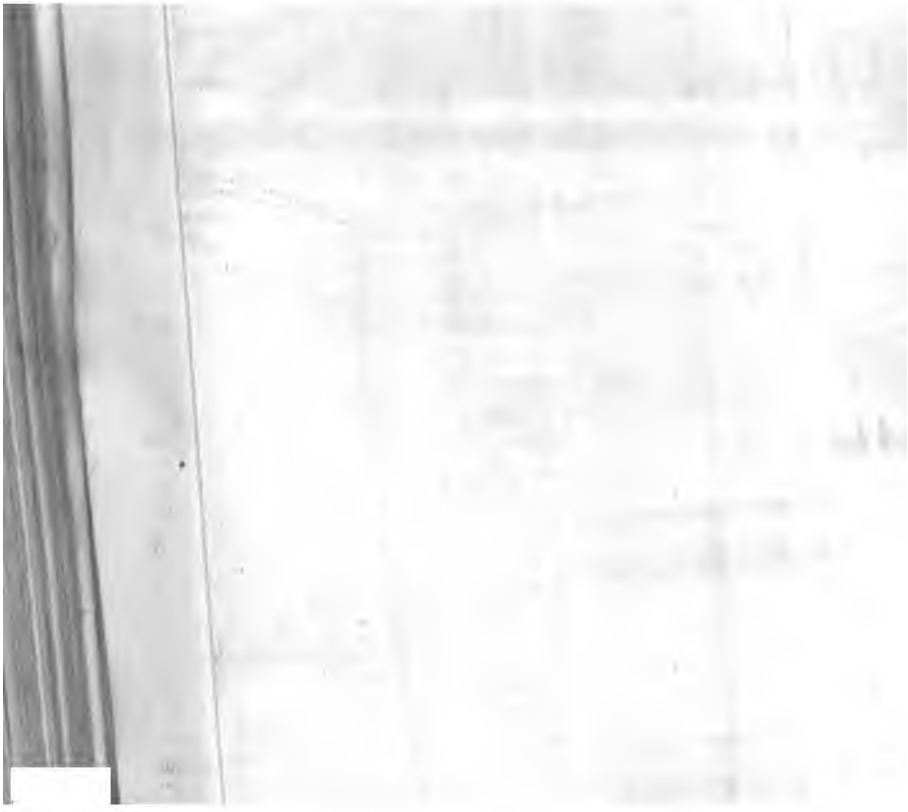

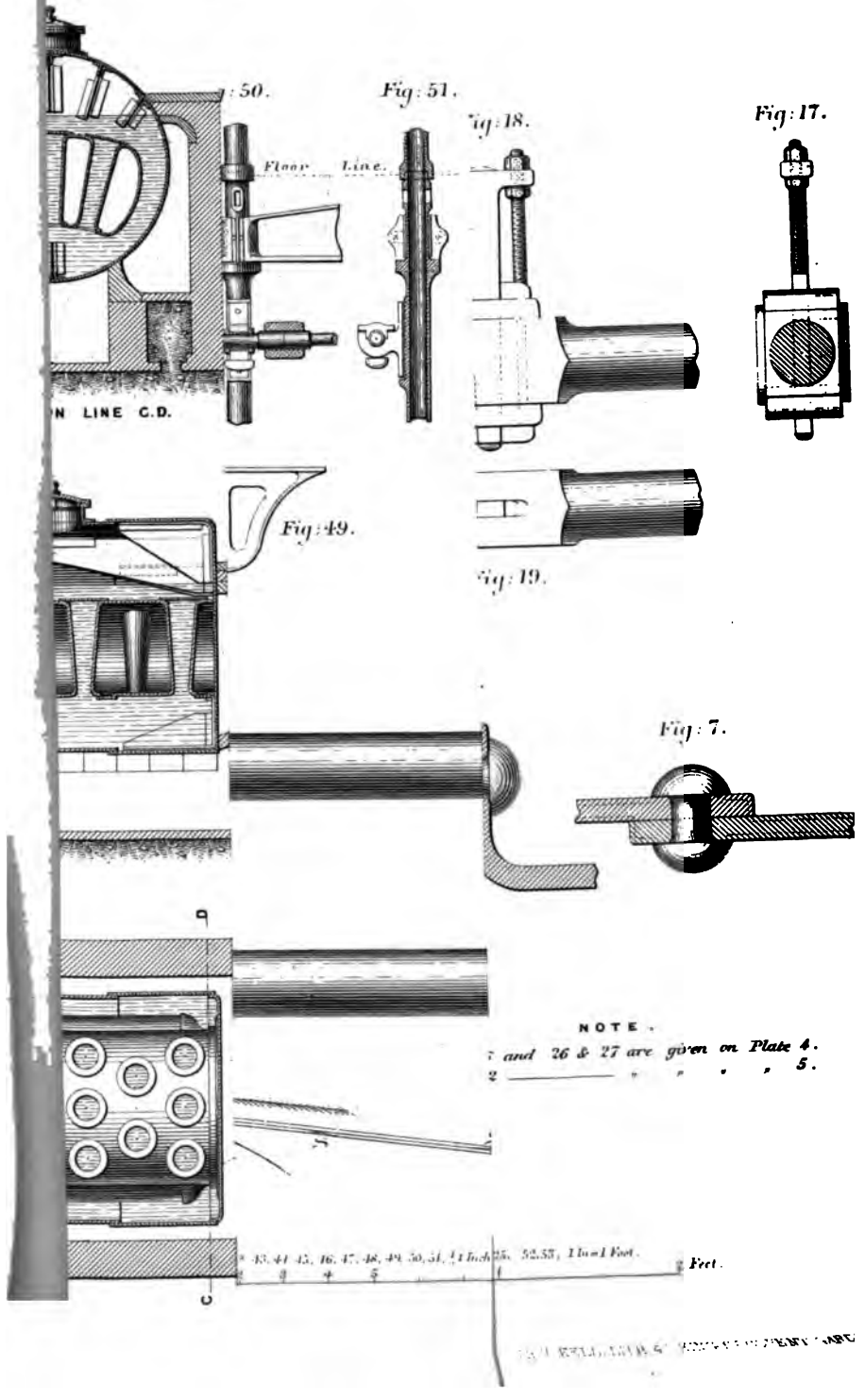
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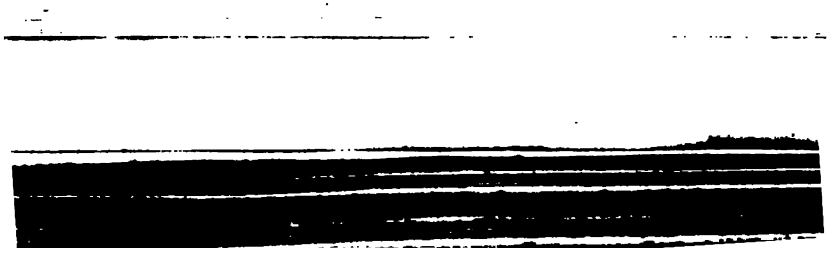

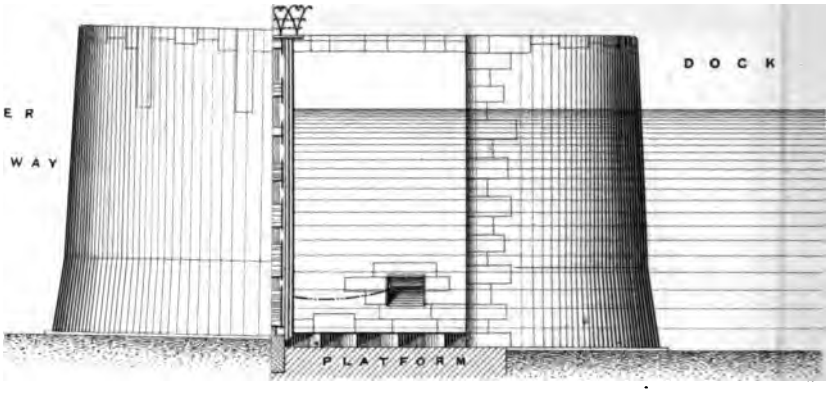

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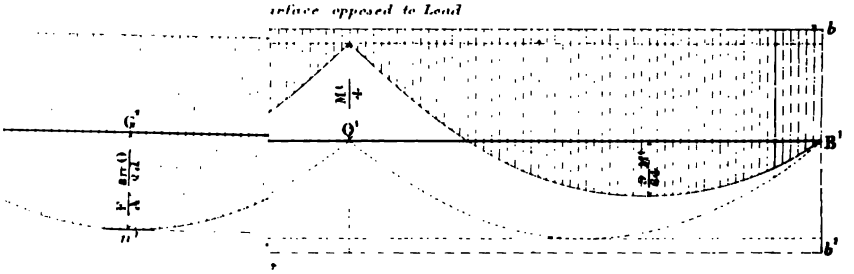

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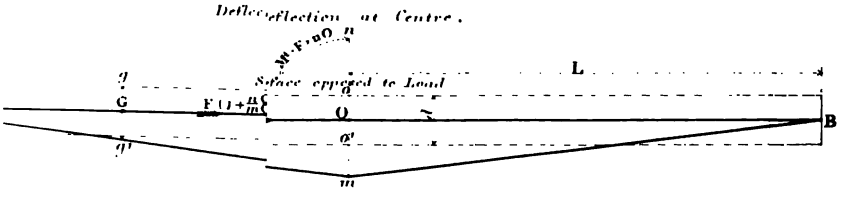

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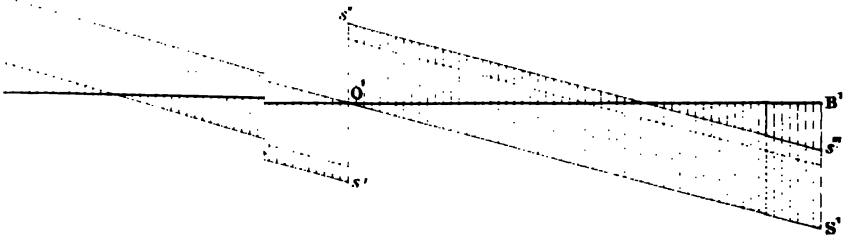

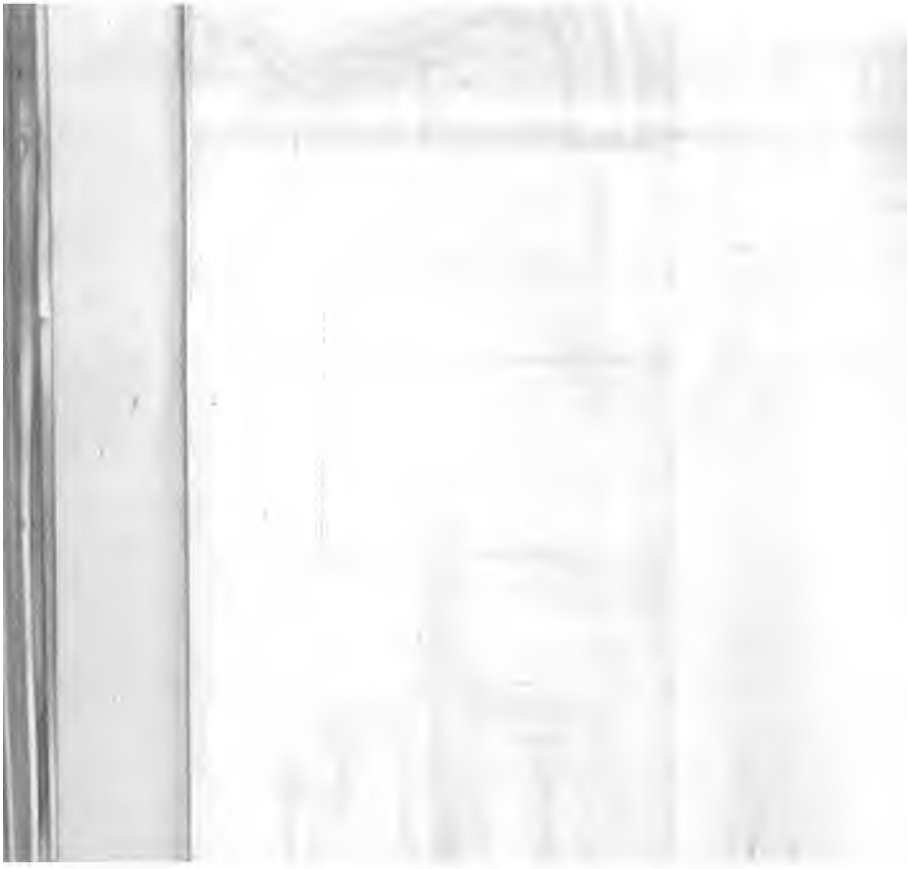

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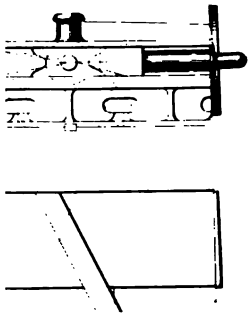

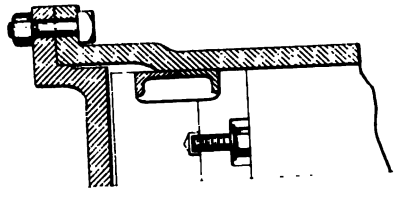

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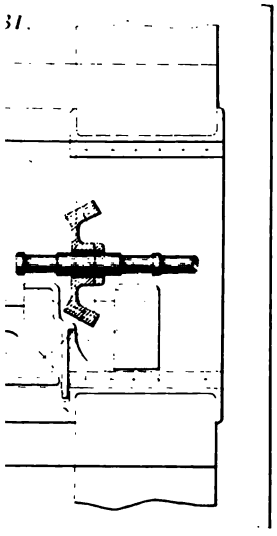

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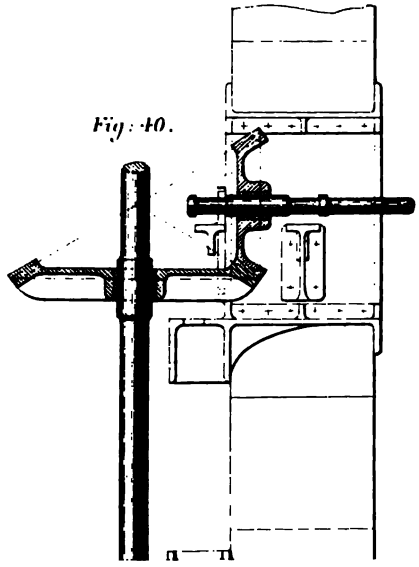

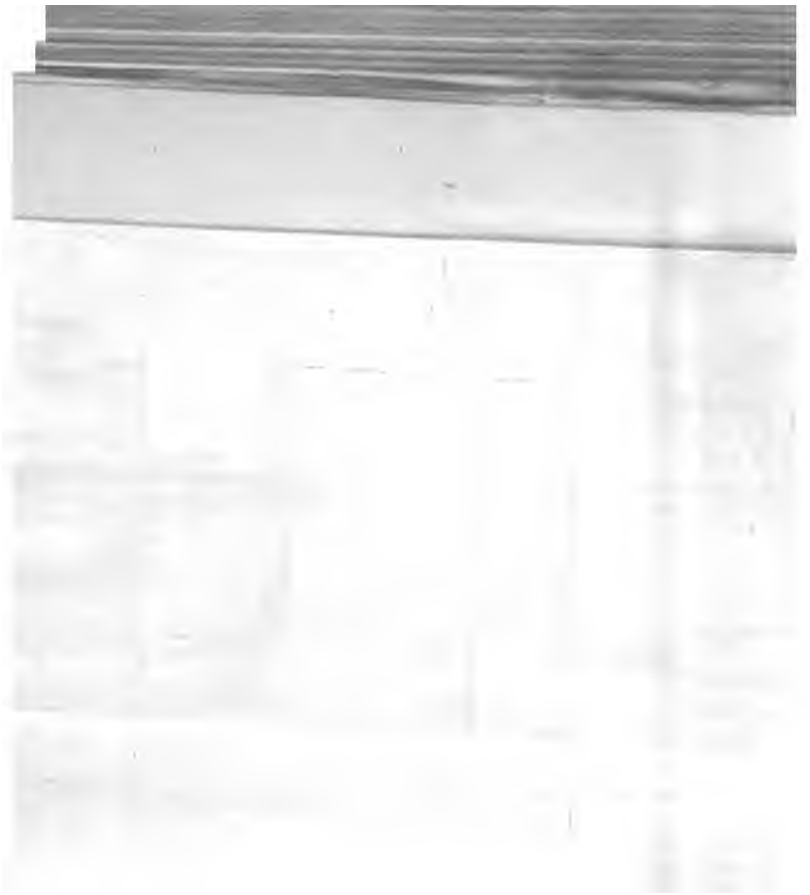

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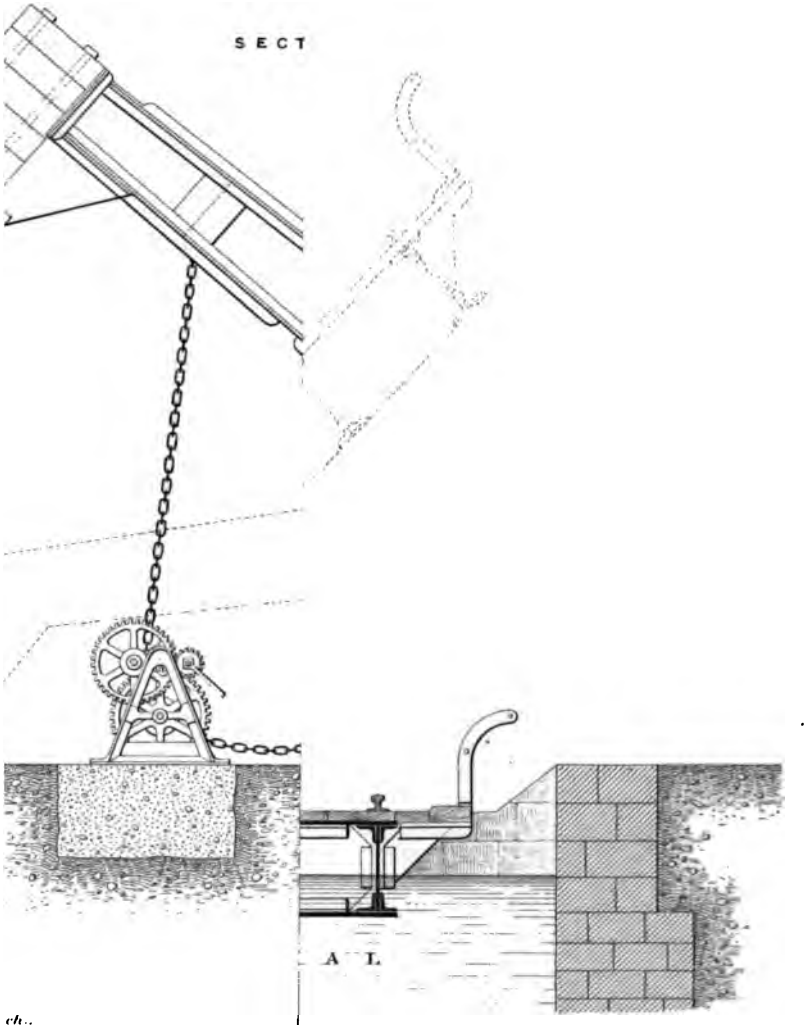

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THOS KELLY,LITH 40,KING ST COVENT GARDEN.

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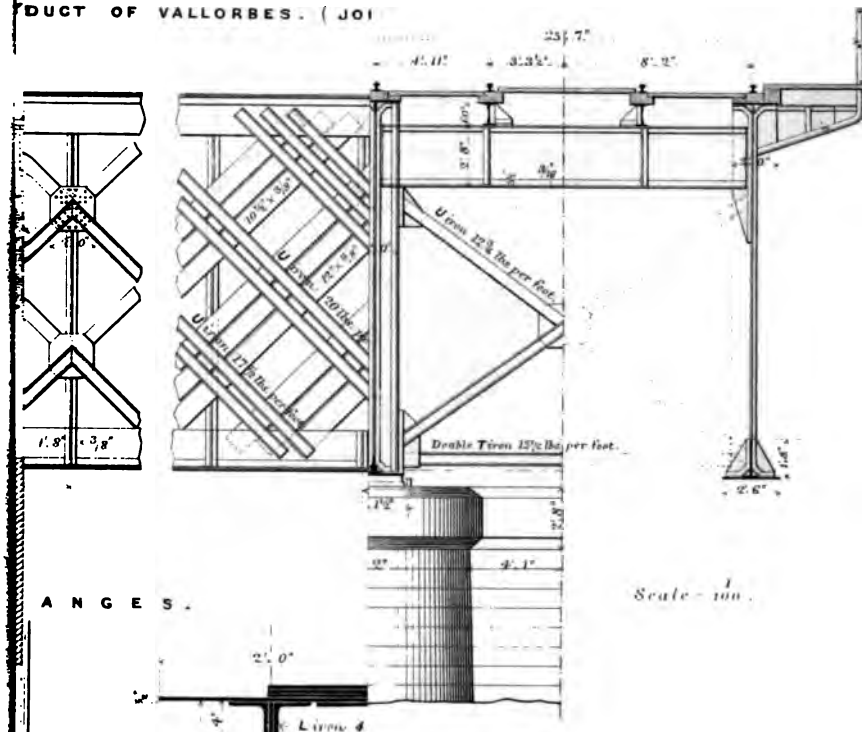

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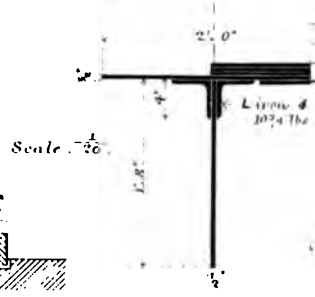

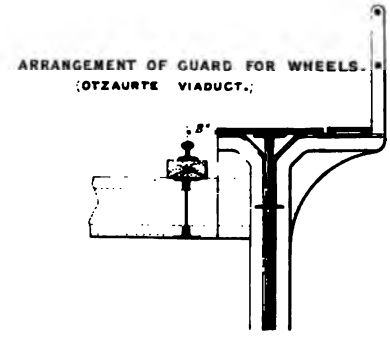

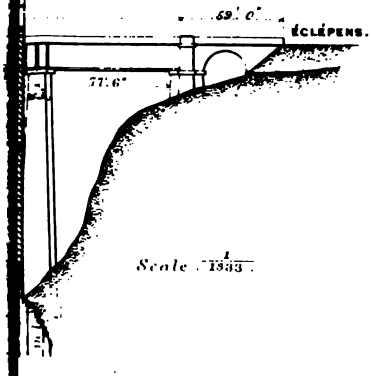

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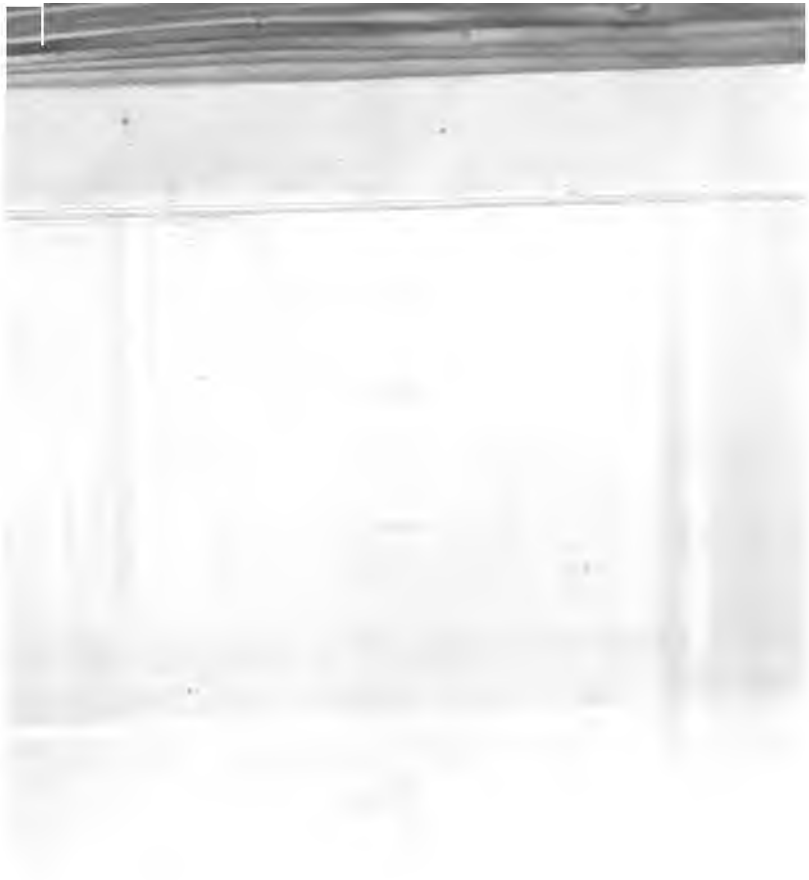
THOS KELL. LITH 40 KING ST COVENT GARDEN



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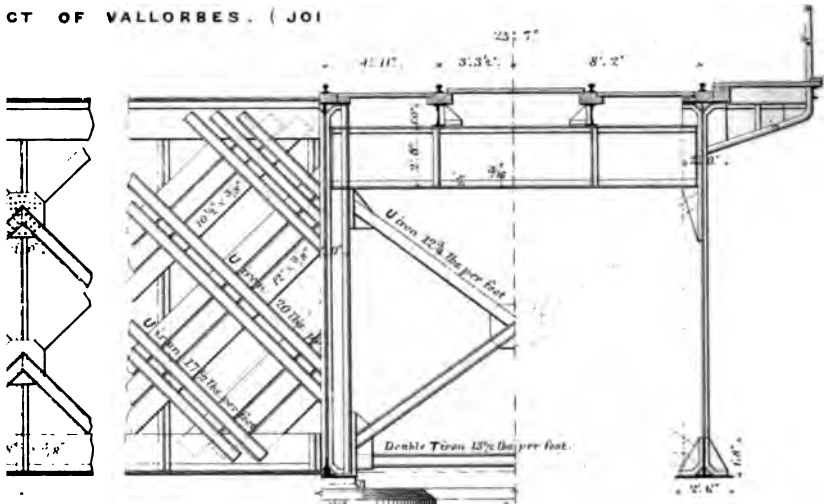

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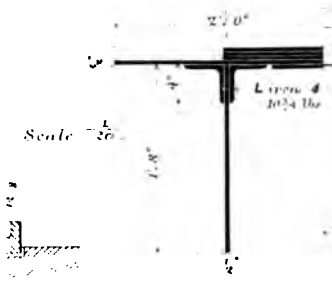

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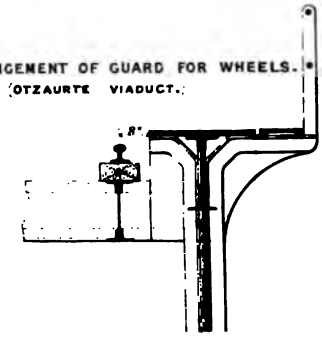

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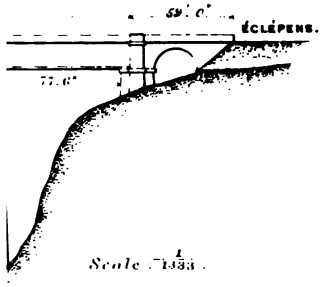

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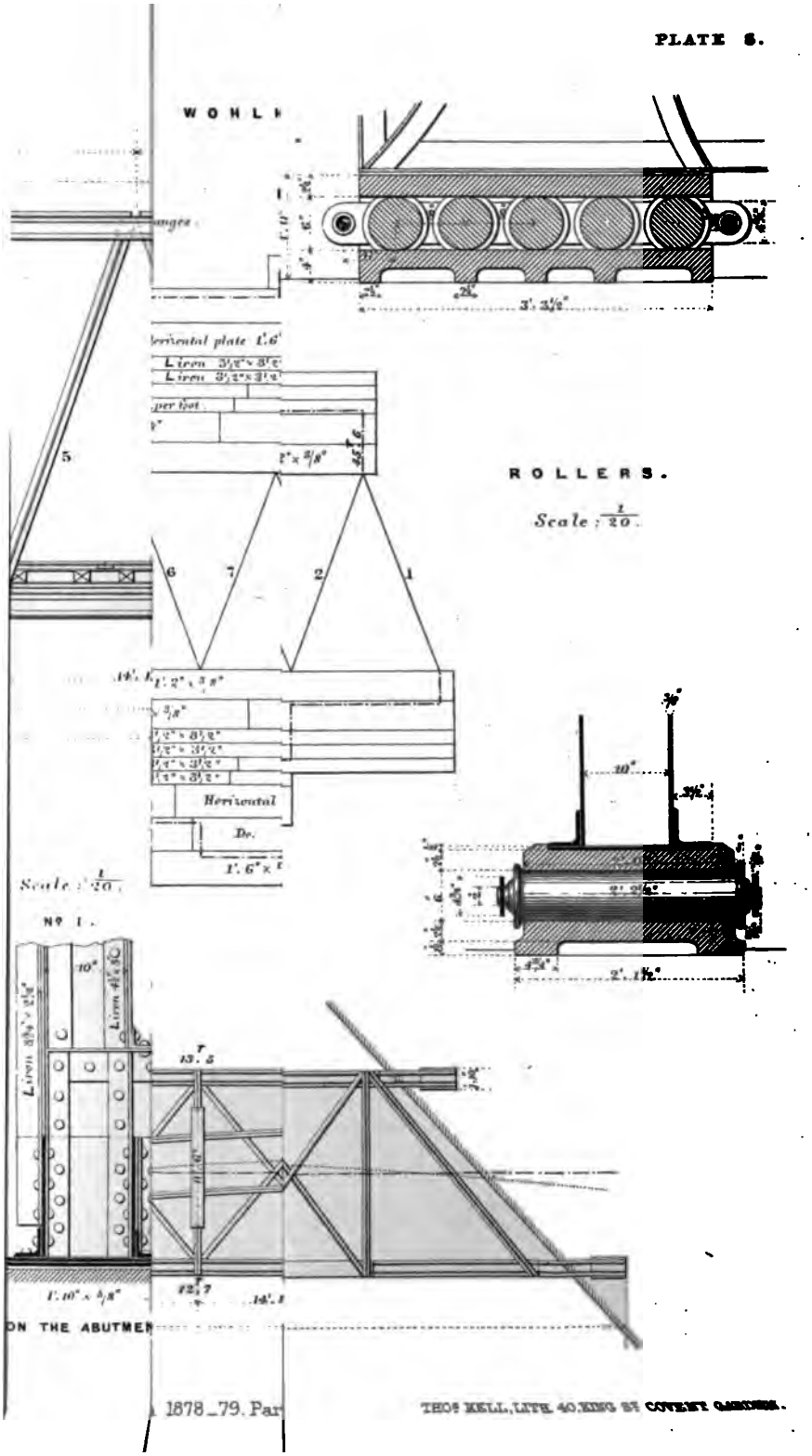

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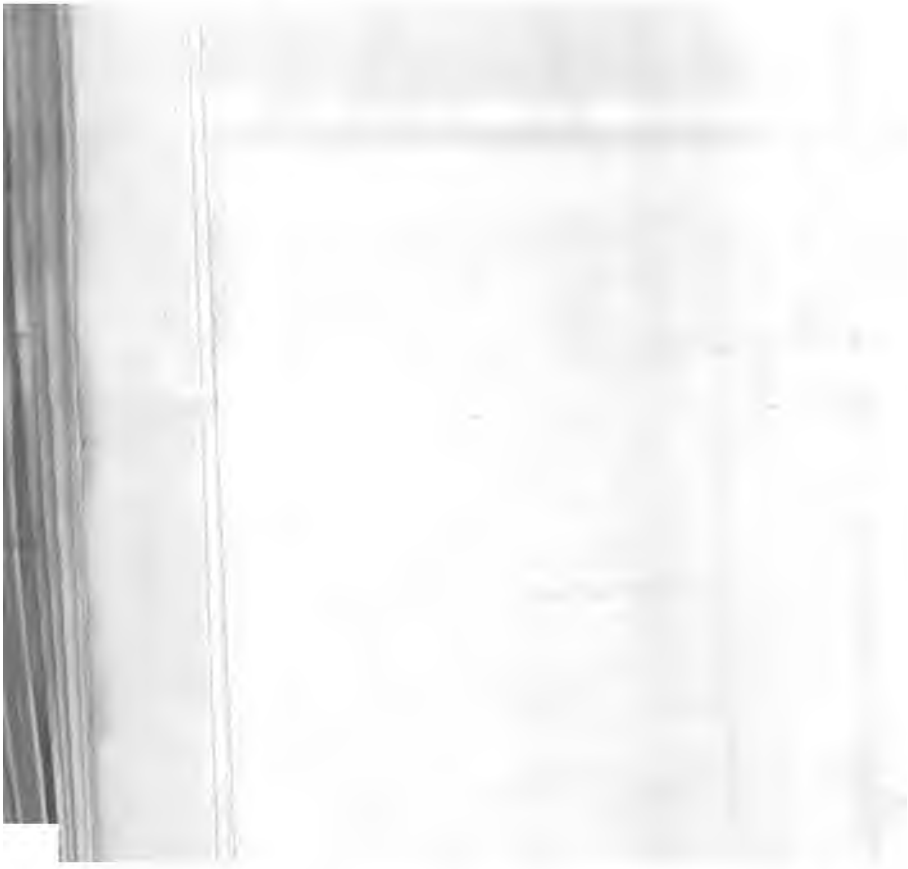

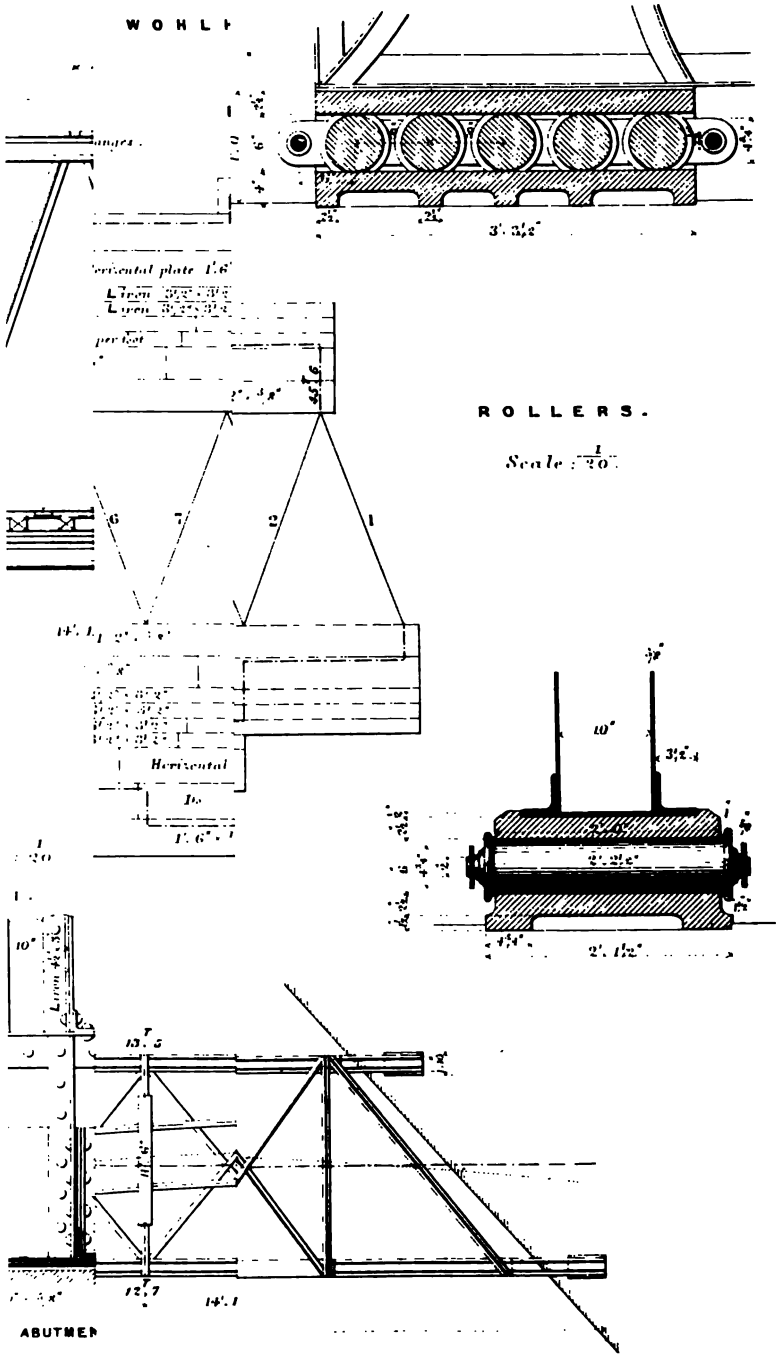

THOS KELL LITH 40 KING ST COVENT GARDEN

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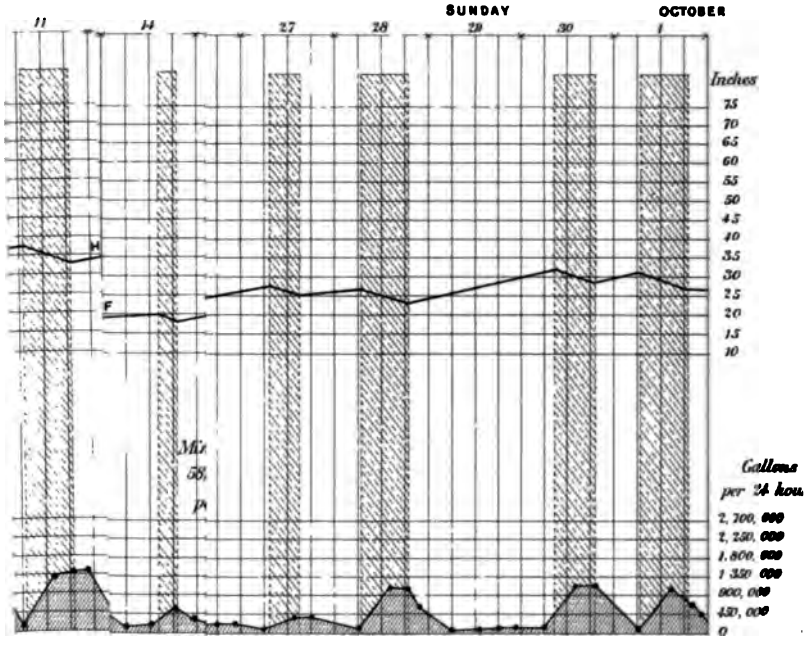

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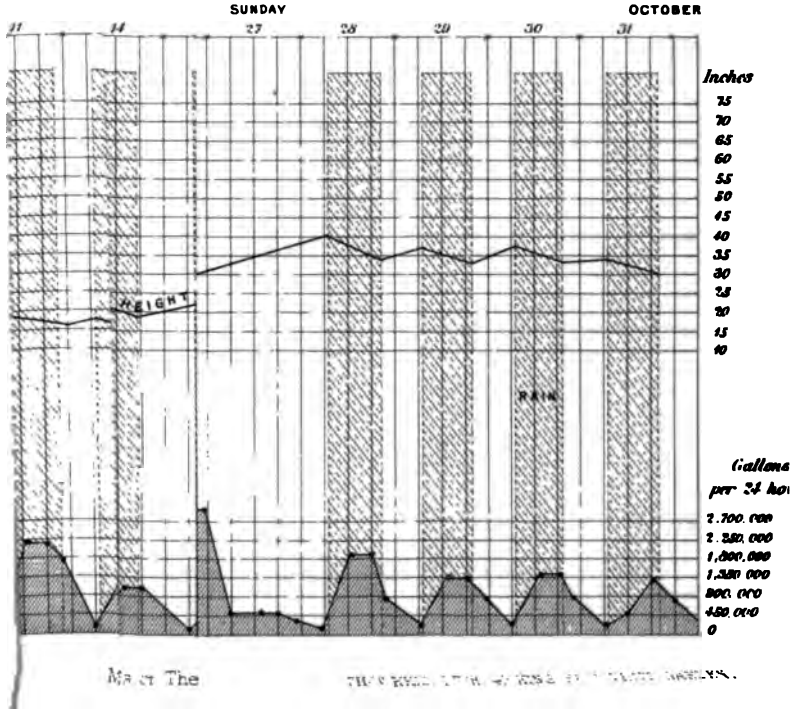

Mr. C. The